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BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE:
TORONTO, 1924.

THE PRESIDENTIAL ADDRESS.

PREVENTION OF DISEASE.

BY

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MY first duty is to thank the General Committee of the British Association for the great honour they have done me by electing me to the post of President. I must confess I wondered at first why I had been chosen, but soon came to the conclusion that it was an honour done through me to all Army Medical Officers for the magnificent work done by them during the Great War, in the prevention of disease and alleviation of pain and suffering.

In the next place, I may be permitted to remind you that this is the fourth time the British Association for the Advancement of Science has met in Canada—first in 1884 in Montreal, in this city in 1897, and in Winnipeg in 1909.

The addresses given on these occasions dealt with the advancement of knowledge in Archæology and Physics.

It is now my privilege, as a member of the medical profession, to address you on the advances made during the same period in our knowledge of disease and our means of coping with and preventing it.

An address on the prevention of disease at first sight does not promise to be a very pleasant subject, but, after all, it is a humane subject, and also a most important subject, as few things can conduce more to human happiness and human efficiency than the advancement of knowledge in the prevention of disease.

Think for a moment of the enormous loss of power in a community through sickness. Some little time ago the English Minister of Health, when emphasising the importance of preventive work, said that upwards of 20,000,000 weeks of work were lost every year through sickness, among insured workers in England. In other words, the equivalent of the work of 375,000 people for the whole year had been lost to the State. When to that is added the corresponding figure for the non-insured population you get some idea of the importance of preventive work.

Another way of estimating the value of prevention is in terms of dollars, or pounds, shillings, and pence, and it has lately been calculated that the direct loss in England and Wales from sickness and disability amounts to at least 150,000,000*l*. a year. In the United States, with a much larger population, the loss is put down at 600,000,000*l*.

Another reason why this is an important subject is that medicine in the future must change its strategy, and instead of awaiting attack must assume the offensive. Instead of remaining quietly in the dressing stations and field hospitals waiting for the wounded to pour in, the scientific services must be well forward in the enemy's country, destroying lines of communication, aerodromes, munition factories, and poison-gas centres, so that the main body of the army may march forward in safety.

It must no longer be said that the man was so sick he had to send for the doctor.

The medical practitioner of the future must frequently examine the man while he is apparently well, in order to detect any incipient departure from the normal, and to teach and urge modes of living conformable to the laws of personal health, and the Public Health authorities must see to it that the man's environment is in accordance with scientific teaching.

It may be a long time before the change is widely accepted, but already enormous advances have been effected, and it only depends on the intelligence and education of the populations how rapid the future progress will be.

Public opinion must be educated to recognise that most diseases are preventable and to say with King Edward VII., 'If preventable, why not prevented?'

To our forefathers disease appeared as the work of evil spirits or magicians, or as a visitation of Providence to punish the individual or the community for their sins.

It is not my purpose to give a detailed account of the first strivings after a better knowledge of the causes of disease, but it may be said the new era began some few hundred years ago, when it was recognised that certain diseases were contagious.

For a long time it was held that this contagion or infection was due to some chemical substance passing from the sick to the healthy, and acting like a ferment; and then, about the middle of last century, the idea gradually grew that microscopic creatures might be the cause.

About this time it had been discovered that the fermentation of grape

juice was caused by a living cell and that certain contagious skin-diseases were associated with living fungi.

Things were in this position when there appeared on the scene a man whose genius was destined to change the whole aspect of medicine; a man destined to take medicine out of the region of vague speculation and empiricism, and set its feet firmly on new ground as an experimental biological science. I mean the Frenchman, Louis Pasteur. It is from him we date the beginning of the intelligent, purposive prevention of disease. It was he who established the germ theory, and later pointed the way to the immunisation of man and animals, which has since proved so fruitful in measures for the prevention or stamping out of infectious diseases.

I need not discuss his life and work further. His name is a household word among all educated and civilised peoples. Every great city should put up a statue to him, to remind the rising generations of one of the greatest benefactors of the human race.

What the change in medicine has been, is put into eloquent language by Sir Clifford Allbutt: 'At this moment it is revealed that medicine has come to a new birth. What is, then, this new birth, this revolution in medicine? It is nothing less than its enlargement from an art of observation and empiricism to an applied science founded upon research; from a craft of tradition and sagacity to an applied science of analysis and law; from a descriptive code of surface phenomena to the discovery of deeper affinities; from a set of rules and axioms of quality to measurements, of quantity.'

With one notable exception, the medical profession were not quick to see that Pasteur's discoveries of the nature of fermentation and putrefaction had a message for them. This exception was Joseph Lister, who had been for some years endeavouring to comprehend the cause of sepsis and suppuration, which commonly followed every surgical operation and most serious injuries involving a breach of the skin.

When, in 1865, Lister read Pasteur's communication upon fermentation, the bearing of the discovery on the problems which had so earnestly engaged his attention was apparent to him. He inferred that suppuration and hospital gangrene, the causes of which had so far baffled his imagination, were due to microbes introduced from the outside world, from the air, and by instruments and hands of the operator. Remember, this was years before the microbial causation of any disease was established.

To test the correctness of his inference, Lister proceeded to submit all instruments, ligatures, materials for dressings, and everything that was

to come directly or indirectly into contact with the wound, the hands of the operator, and the skin of the patient, to treatment with chemical disinfectants.

The satisfactory results which followed this practice astonished even Lister, and he spent the rest of his active life in improving and simplifying technical methods of preventing the ingress of microbes to wounds, and in convincing his professional brethren of the truth of the conclusions based on this work of Pasteur.

INFECTIOUS DISEASES.—(A) BACTERIAL.

As soon as it was recognised that infectious diseases are caused by living germs a wave of enthusiasm swept through the medical world, and it was not long before the causation of many of the most important of them was discovered. I need not give a full list of these, but at or round about the time of the first meeting of the British Association in Canada the micro-organisms of tuberculosis, typhoid fever, Malta fever, cholera, malaria, diphtheria, tetanus, and others had been discovered and described.

But it must not be assumed from what has been said that all the most important diseases are caused by living germs. Many of the ills that afflict mankind are due to quite other causes. Alcoholism, for example, or the deficiency diseases, due to the absence or deficiency in our diet of some substance essential to proper growth and development. Rickets, one of the greatest scourges of industrial communities, is mainly a deficiency disease. It is reported that as many as 50 per cent. of the children in the slums of some of our big cities suffer from the effects of this disease.

Then again, there is the whole series of diseases or conditions due to defective or excessive action of our own internal glands.

Added to these, and perhaps the greatest scourge of all, there is the immense amount of chronic ill-health and actual disease caused or promoted by the unhealthy conditions found in our large cities, due to bad housing and overcrowding—the so-called diseases of environment.

Malta Fever.

But to return to the infectious diseases. After the living germs or parasites causing them had been isolated the process of prevention was soon begun. The methods employed were varied, and I may illustrate one of the simplest by relating briefly the history of the prevention of Malta fever, with which I was myself, to some extent, associated.

Malta fever is really a widespread disease, although it is called by a local name. It is found all round the Mediterranean, throughout Africa as

far south as the Cape Province, in India and China, and even in some parts of America. It was very prevalent in Malta in the old days, and rendered the island one of the most unhealthy of all our foreign military stations. When I arrived in Malta, in 1884, I found that every year, on an average, some 650 soldiers and sailors fell victims to it, and, as each man remained on an average 120 days in hospital, this gave the huge total of about 80,000 days of illness per annum from this fever alone.

The British had held Malta since the beginning of last century, and, although much attention had been given to the fever and its symptoms had been fully described, no advance was made towards its prevention until 1887, when the living germ, the *Micrococcus melitensis,* causing it was discovered.

At this time a good deal of work was expended in studying the natural history of the fever and the micrococcus, but all to no purpose. Nothing was discovered to give a clue to any method of prevention.

At the Naval Hospital especially everything in the way of prevention was done that could be thought of: the water supply and drainage were thoroughly tested, the walls were scraped and every corner rounded off where dust might lie, immaculate cleanliness reigned; but all these precautions proved useless. Almost every sailor who came into the hospital even for the most trivial complaint took Malta fever, and after a long illness had to be invalided to England.

Things remained in this very unsatisfactory state for seventeen years, until 1904, when the Admiralty and War Office, alarmed at the amount of sickness and invaliding in the Malta garrison, asked the Royal Society of London to undertake the investigation of the fever. This was agreed to, and a Commission was accordingly sent out in the same year and remained at work until 1906.

During the first year every likely line of approach was tried. A careful study was made as to how the micrococcus entered the body, how it left the body, its behaviour outside the body, its pathogenic action on various animals; but still no indication of a method of prevention showed itself.

Next year, however, in 1905, the problem of prevention was solved, and that by the merest of accidents.

In the previous year experiments had been made with the object of finding out if the goat, among other animals, was susceptible to the disease. The goats in Malta, which supply all the milk, are very much in evidence, as they are driven about in small herds and milked as required at the doors of customers. Several goats had been injected with cultures of the micro-

coccus, but, as they showed no rise of temperature or any signs whatever of ill-health, they were put aside as being immune or refractory to the disease and nothing more was thought about them.

In the spring of 1905, about six months after these experiments had been made, Dr. Zammit, a Maltese member of the Commission, who had kept one of two of these goats, happened for some reason or other to examine their blood, and found that it clumped or agglutinated the micrococcus. This was strange, and seemed to show that, although the micrococcus had not caused fever or any signs of illness in the goats, it must have lived and multiplied in the tissues of these animals in order to have brought about this change in the blood.

This observation led to the re-examination of the immunity of the goat, when the extraordinary discovery was made that about 50 per cent. of the goats in the island were affected by this disease, and that 10 per cent. of them were actually excreting the micrococcus of Malta fever in their milk.

Monkeys fed on milk from an affected goat, even for one day, almost invariably took the disease.

Thus the weak link in the chain of causation had been found. The military authorities struck Maltese milk out of the dietary, and replaced it by an imported variety, and from that day to this there has scarcely been a case of Malta fever in the garrison. Malta, from being the most unhealthy of foreign stations, became a health resort, and was in fact used as a sanatorium during the late war. The disease had been blotted out at a single blow.

This, then, is one way of preventing an infectious disease; that is to say, by the discovery of the living germ, the study of its natural history, and so to a means of stopping it reaching its victim, man. This is the best way of prevention: shutting the stable door before the horse is stolen.

Typhoid Fever.

But there are other ways of preventing bacterial diseases. Let us take, for example, a method widely used in the prevention of typhoid fever.

The fundamental and sound way of attacking this disease is by ordinary hygienic measures, especially a good water supply and good drainage. It is therefore one of the first duties of those in power to see that their people have, in addition to houses with plenty of light and air, a good water supply and a good drainage system, and money cannot be spent to better advantage than in the attainment of these three essentials to health.

When typhoid fever is rife in a community it means that there is

either a contaminated water supply or a faulty drainage system, and the municipal authorities ought to be called to account. In England, owing to improved sanitation, cases of typhoid fever are fifteen times less than they were fifty years ago.

But it is not always possible to ensure good hygienic surroundings—for example, among troops on active service. It is therefore legitimate under certain conditions, and especially in time of war, to practise a less sound, a less fundamental, method of prevention, and this second method is known as inoculation or vaccination.

In order to understand how this acts, let us consider, for a moment, what takes place in a man's body when he is attacked by the typhoid bacillus. Everybody knows that the bacillus gives rise to poisons or toxins which cause the fever and other symptoms. But the cells and tissues of the man are not passive under the attack. They at once begin to fight against the infection, by forming substances in the blood to neutralise these toxins, hence called antitoxins or antibodies, and their function is finally to destroy the invading germs. If the man recovers he is immune from a further attack by the presence of these antibodies in his blood. He has become immune by passing through an attack of the disease.

This is the foundation of the second way of preventing infectious diseases. Speaking broadly, it means that you subject a man to a mild attack of the fever in order that his blood and tissues will respond to the stimulus by producing antibodies.

This method takes its origin and name from that of vaccination against smallpox. Jenner solved that problem by the accidental discovery of vaccinia, a form of smallpox attenuated or weakened by passage through another species of animal. This weakening of the virulence of a micro-organism by passage through another kind of animal is by no means uncommon in nature.

Pasteur, following on these lines, conceived the idea of weakening or attenuating the virulence of the living bacilli by artificial means, so as to give rise to a mild attack of the disease, and in this way to render animals immune. This he did with marked success in anthrax and chicken cholera.

The next forward step in this method of preventing disease was made by Haffkine, a pupil of Pasteur, who about the year 1894 produced a vaccine against cholera, and a few years later another, against plague.

In the course of this work it was discovered that it was not necessary to use living cultures of the bacilli, but that vaccines made up of dead

bacilli had much the same effect. This substitution of the dead bacilli for the living was a great advance in the method, being much simpler and much safer.

The next disease to be attacked by this method was typhoid fever. This was initiated by Sir Almroth Wright at the British Army Medical School, and carried out with that scientist's characteristic ability and energy. The method was mainly directed in the first place to lessen the mortality from this disease among our soldiers serving in India.

After several years' experience, the mode of inoculation which was finally settled on was to give two injections of dead typhoid bacilli, one of 500 millions, and a second, at an interval of ten days, of a thousand millions.

Now let us see what effect anti-typhoid inoculation has had on the prevention of typhoid fever among our soldiers in the field.

In the South African War, at the beginning of the century, before the method had been developed, in an army the average strength of which was only 208,000 there were 58,000 cases of typhoid fever and 8,000 deaths.

In the Great War, on the Western Front, with an average British strength of one and a quarter millions, there were only 7,500 cases and 266 deaths. In other words, there were fewer cases of the disease in this war than there were deaths in the South African.

It is also interesting to learn from French sources that at the beginning of the war the French soldiers were not inoculated, whereas the British were. The result for the first sixteen months was striking. During this time the French had some 96,000 cases, with nearly 12,000 deaths. The British had only 2,689 cases and 170 deaths. Afterwards the French soldiers were very thoroughly vaccinated, with the result that their immunity eventually became as striking as our own.

What the number of cases and death-rate from typhoid fever might have been in the huge armies fighting on the different fronts had it not been for this preventive inoculation it is impossible to say, but undoubtedly the suffering and loss of life would have been enormous.

I may therefore conclude this account of anti-typhoid inoculation by saying that it certainly constituted one of the greatest triumphs in the prevention of disease during the recent war.

Tetanus and Diphtheria.

I shall now pass on to consider a third method of preventing bacterial diseases which has also been evolved during the time under review; that is, by the injection of specially prepared blood sera. These are known

as antitoxic sera, and the most familiar examples are anti-tetanic and anti-diphtheritic.

We have seen how the injection of living or dead bacilli or their toxins into animals gives rise to the production of antibodies or antitoxins. The blood serum of such animals in virtue of the antibodies contained in it can be used to combat disease.

Let us take in the first place the case of tetanus, until recently considered to be one of the most fatal of maladies, at least 85 per cent. of the cases succumbing.

As you are aware, anti-tetanic serum is prepared by injecting horses with large quantities of tetanus toxin. When the blood is as full as possible of antibodies it is drawn off and the serum allowed to separate out.

The idea lying behind this third method of preventing disease is to pour in these ready-made antitoxins in order to assist the body in its first struggle with the invading disease, and give it, as it were, a breathing space to prepare its own defences.

Naturally the immunity produced by these antitoxic sera is of a passive nature, and of short duration, as compared with that produced by the disease itself, or even by the milder form brought about by vaccination or inoculation.

Anti-typhoid inoculation will protect a soldier for, let us say, two years; anti-tetanic serum will protect for only a week or ten days. It is therefore impossible to inoculate a whole army against tetanus. It is necessary to wait until there is a danger of the disease occurring.

To illustrate this I shall describe briefly the history of the prevention of tetanus during the Great War.

When the British Expeditionary Force went over to France, in August 1914, only a small quantity of anti-tetanic serum was taken, and that for the purpose of treatment rather than prevention. But shortly after the outbreak of hostilities the number of cases of tetanus among the wounded became so alarming that no time was lost in grappling with the danger. Large quantities of serum were hurried to the front, and some two months after the beginning of the war it was possible to make an order that every wounded man should receive an injection of anti-tetanic serum as soon after he was wounded as possible. Later on, after further experience had been gained, the single injection was increased to four, given at intervals of a week. This helped the wounded man over the dangerous time and the results were very successful.

In August and September 1914, before the prophylactic injection was

given, roughly speaking nine or ten out of every thousand wounded were attacked by tetanus and some 85 per cent. of these died.

After the anti-tetanic injections had been introduced the incidence fell to little more than one per thousand, and the mortality to less than half.

To put the matter broadly: during the war there were 2,500 cases of tetanus in the British Army, with 550 deaths. If there had been no prophylactic injection of anti-tetanic serum there would probably have been 25,000 cases with 20,000 deaths—a very striking example of the recent development in the prevention of disease.

Another very important and widespread disease, somewhat resembling tetanus, is diphtheria, and there is no better example of the advance of science in methods of cure and prevention than is found in this disease.

Thanks to the work of Klebs and Löffler in the early 'eighties and, some years later, to the brilliant researches of Roux and Yersin, the causation and natural history of this disease were very thoroughly elucidated.

Anti-diphtheritic serum is prepared much in the same way as the anti-tetanic. By the repeated injections of gradually increasing doses of the bacilli or their toxins, a serum is produced which has a marked curative effect in cases of diphtheria.

It is stated that the introduction of anti-diphtheritic serum in 1894 has reduced the death-rate from 40 to 10 per cent., and if used on the first day of the disease to almost *nil*.

The serum is essentially a curative agent and is useful only to a limited extent in prevention.

But lately essentially preventive measures in diphtheria have come into vogue. The procedure employed is to bring about an active immunisation by a mixture of toxin and antitoxin in individuals who have been shown to be susceptible to the disease by what is known as the Schick test.

In the United States a campaign on these lines has been begun against this disease which promises brilliant results. It is confidently stated that by their new measures there is a possibility of robbing diphtheria of all its powers to kill or injure.

The mode of prevention of these diseases—Malta fever, typhoid fever, and tetanus—illustrates the three principal methods of preventing bacterial diseases: in Malta fever, by getting down to bed-rock and stopping the disease at its source; in typhoid fever, by giving, as it were, a mild attack of the disease, by vaccination or inoculation, so as to bring about a greater

power of resistance; in tetanus, by pouring in antitoxins, already prepared in the serum of another animal, in order that they may neutralise the toxins of the invading bacilli as soon as they are formed.

Tuberculosis.

There are other important bacterial diseases, however, which cannot be attacked so simply. For example, there is tuberculosis, a disease distributed over the whole world and one of the greatest scourges of civilised communities. It is a disease which has been known from time immemorial, but it is only within our own time that the bacterial cause has been recognised. I can well remember a day in 1882 when I met a fellow student who had just returned to Edinburgh from Germany. He told me that it had been recently discovered that the disease was really caused by a living germ, the tubercle bacillus. It was difficult at first to believe such a revolutionary idea, but such was the interest and excitement raised that many workers at once took up the study of the subject and in a short time the truth of Koch's great discovery was fully proved. This was a magnificent example of research work, most admirably, carefully, and completely carried out, and placed Koch at once in the front rank of scientific workers.

Before Koch's discovery a good deal had been done in the way of prevention. Before all things, this disease is a disease of environment. Its birthplace and home is the sunless, ill-ventilated, overcrowded room. The late Professor Edmund Parkes, Professor of Hygiene at the Army Medical School, reduced to a great extent the incidence of tuberculosis in the British Army by procuring for the soldier more floor-space and more air-space in his barracks. It is related of General von Moltke that when he heard of the death of Parkes he said that every regiment in Europe should parade on the day of his funeral and present arms in honour of one of the greatest friends the soldier ever had.

The prevention of tuberculosis is thus seen to depend fundamentally on the provision of a better environment and the education of the people in physiological living.

To attain this in the older civilisations will be a hard task, entailing enormous expenditure of money and energy. In the Report of the Royal Commission on the Housing of the Industrial Population of Scotland in 1917 is described the unsatisfactory sites of houses and villages, insufficient supplies of water, unsatisfactory provision for drainage, the gross overcrowding in the congested industrial towns, occupation of one-room houses

by large families, groups of lightless and unventilated houses in the older burghs, clotted masses of slums in the great cities—a terrible picture, the heritage of the age of ignorance, internal strife, and walled towns.

The people of new countries should see to it, and doubtless will see to it, that these old evils are not perpetuated.

As Sir Robert Philip, Professor of Tuberculosis in the University of Edinburgh, has eloquently said: 'Were it possible to begin afresh the scheme of civilised life, were it possible to undertake anew the creation of cities and the homes of our people, were it possible to place within the re-created dwellings an understanding race, de-tuberculisation might be quickly attained. What a magnificent opportunity for the builders of the new cities, the moulders of fresh civilisations, with the grand purpose of "No tuberculosis." The architect, the sanitarian, and the citizen would agree in insisting that physiological laws should be paramount, that there should be effective obedience to the larger demands of hygiene in the home, the school, the workshop, the meeting-place and the cow-shed.

'Mankind was born into air and sunlight: these are his natural heritage. They are more—they are the irreducible conditions of life.'

In regard to the tubercle bacillus it is so widespread, so ubiquitous in civilised communities, passing from one infected host to infect another, that it would seem impossible under existing conditions to prevent its spread. At present it is taught, and on what seems good evidence, that the majority of the population of our crowded cities has at one time or another been attacked by this disease. But in every hundred men who die in England, only about ten die of tuberculosis, which shows that a large percentage of the population successfully resists the tubercle bacillus.

When this occurs it means that the person attacked possessed powers of resistance which enabled him either to destroy the invading bacilli or deal with them so as to render them harmless.

A point of importance in this connection is that it has recently been demonstrated that the disease is usually acquired in childhood. The fact is of capital significance, for if the disease is recognised sufficiently early, and the child is placed under good hygienic conditions, there is a very good chance of effective resistance and immunity against a second attack being set up.

The present evidence goes to show that the presence of latent tubercle prevents a second invasion. If further outbreaks take place, they would seem to be due to a flaring up of the old latent tubercle rather than to a fresh infection.

Metchnikoff studied the question in a remote part of Siberia where the tubercle bacillus was unknown. He states that very many of the young men and women who migrated from this clean country into the big cities died of acute and rapid tuberculosis, on account of not having been exposed to infection in their childhood.

The experience of Colonial troops in the late war is instructive. Thus, in France the Senegalese, who are almost without tuberculosis in their native condition, and were found to be free from tuberculosis on reaching France, developed in large numbers an acute and fatal form of tuberculosis in spite of the hygienic measures enforced by the Army authorities.

This raises a curious point. If it were possible for any country to clear itself of the tubercle bacillus, it would appear to be incurring a great risk for an inhabitant to migrate into any neighbouring country.

But, in spite of this, it is the duty of medical men to keep in check, as far as possible, the ravages of the disease.

The preventive measures against tuberculosis at the present time are, in the first place, improvement in the general hygienic conditions. Thereby individual resistance—and communal resistance—can be remarkably increased.

In the second place, as every case of tuberculosis must arise from a previous case, either human or bovine, it is very necessary that methods of early diagnosis, preventive treatment, and segregation of the more infective types should be employed. This is done by the setting up of tuberculosis dispensaries, care committees, sanatoria, hospitals and colonies. These several elements are combined in the model Tuberculosis Scheme which is now universal throughout Great Britain.

In the third place, much can be done to anticipate and limit the progress of infection by the use of tuberculin, but caution is required in assessing the claims, sometimes hasty and extravagant, advanced by adventurers in this field of research.

Many other points might be brought forward, but the subject is such a vast one that I must content myself with drawing attention to the importance of a sound milk supply.

The contamination of our home herds with tuberculosis is so great that no pains should be spared to secure a safe milk supply, and I understand that the city of Toronto is a model in this respect.

The result of these methods of prevention against tuberculosis may be given briefly. Sir Robert Philip writes that in Scotland ten years before Koch's discovery the death-rate from this disease was 404 per 100,000;

in 1920 it had fallen to 124 per 100,000, a fall of 69·3 per cent. He also points out that the 'recent acceleration of rate of reduction which is noticeable in England and Scotland is of arresting interest.'

'In Scotland the acceleration of fall in the mortality rate likewise arrests attention. Thus, during twenty years up to 1890, the percentage fall in mortality from all forms of tuberculosis was 35, while during twenty years from 1900-1919 the percentage fall was 45.'

This is very satisfactory, and has only been arrived at by hard work on the part of medical men, nurses, and voluntary workers. Any Tuberculosis Scheme, however perfect in theory, will require untiring energy, patience, and perseverance to bear fruit. On this side of the Atlantic, in the United States, these anti-tuberculosis schemes have been pursued with enthusiasm, with the result that Washington in 1920 had a death-rate, from all forms of tuberculosis for 100,000 of the population, of only 85, Chicago 97, and New York 126. London in the same year had a death-rate of 127, practically the same as New York. Other nations have not been so energetic in preventive measures, Vienna having in 1920 a death-rate of 405, and Paris 279 per 100,000 from the same cause.

It is evidently the duty of every nation to take up arms against a disease which exacts such a terrible toll of death, suffering, and inefficiency. If this were done with energy and enthusiasm it is not too much to hope that in a few generations the tubercle bacillus would be practically brought under control, and with it many other malign influences.

INFECTIOUS DISEASES.—(B) PROTOZOAL.

I shall now pass on to the consideration of the second great group of infectious diseases, the Protozoal, and consider what methods of prevention have been found applicable to them.

The scientific study of the protozoal diseases of man may be said to have begun with the epoch-making discovery of the malaria parasites in 1880, by the illustrious Frenchman, Laveran; next, in 1893, the discovery by Theobald Smith and Kilborne of the cause of Texas fever and the part played in its dissemination by the cattle-tick; in 1894 the discovery of the trypanosome of nagana and its intermediate insect host the tsetse-fly; in 1898 the working out of the development of the malaria parasite of birds in the mosquito by Ronald Ross, greatly aided and abetted in the work by Patrick Manson, which led, through the work of Grassi and his fellow workers in Italy, to the final solution of the malaria problem. A year later the important discovery of the mosquito carrier of yellow fever was made

by the American Army Commission, under the directorship of Reed, and in 1903 Leishman announced his discovery of the protozoal cause of kala-azar.

These protozoal diseases are world-wide, like the bacterial, but it is in the warmer climates that their effect is most felt.

The great plagues of the tropics, such as malaria, amœbic dysentery, kala-azar, and sleeping sickness among men, Texas fever, tsetse-fly disease, and others among domestic animals, are caused by minute microscopical animal parasites.

Large tracts of country have been and are still rendered uninhabitable to white settlers by their presence.

The opening up of Africa, for example, was rendered difficult by the tsetse-fly, before the advent of railways. No sooner had an expedition started for the interior than the fly attacked the cattle transport, and before long the expedition had to make its way back as best it could to its base on the coast. The only way to get into the country was on foot with native porters.

The protozoal diseases of domestic animals have also led to enormous loss in all parts of the world. Texas-fever, or red-water, has swept whole countries of their cattle. After the Boer war, South Africa was devastated by the introduction of East Coast fever, another protozoal disease of cattle closely related to Texas fever.

How is the prevention of these diseases to be brought about? We find that up to the present little can be done by way of vaccination or inoculation or by the use of anti-sera as in the bacterial diseases. On studying the natural history of these protozoal parasites, however, it is found that many of them depend on an intermediate insect host for their continued existence, and it is by taking advantage of this characteristic that methods of prevention can be devised.

To illustrate this, I might cite the classical examples of malaria and yellow fever, but, as these must be familiar to you all, I shall take instead the trypanosome diseases of Africa, the best known of which are sleeping sickness in man and nagana or tsetse-fly disease in the domestic animals.

Nagana or Tsetse-fly Disease.

In 1894, a year after Theobald Smith and Kilborne had published their famous monograph on Texas fever, a severe epidemic among native cattle in the north of Zululand was reported to the Natal Government. The disease was called nagana by the natives, and it is curious that there

was no suspicion at the time that it had any connection with the tsetse-fly.

At this time a very enlightened administrator, the late Sir Walter Hely-Hutchinson, was Governor of Natal and Zululand, and it was due to him that the investigation of the cause of the Zululand outbreak was at once undertaken.

As I happened to be stationed in Natal at this time, I was chosen to undertake the work, and at once started on the long journey, mostly by ox-wagon, to the scene of the outbreak.

On examination of the blood of the nagana cattle, a minute active flagellated protozoal parasite, belonging to the genus Trypanosoma, was discovered, and after many experiments on dogs, horses, and cattle it was decided that in all probability it was the cause of the disease.

Trypanosomes had previously been described in the blood of rats and horses in India by Timothy Lewis and Griffith Evans, but nothing was known as to the mode of their transmission from animal to animal.

It seemed as if the discovery of the nagana trypanosome would have ended the investigation in Zululand without any means of preventing the disease being discovered, but another observation made at this time threw more light on the subject.

In the low country between the high ground, on which the nagana camp was situated, and the sea there happened to be a so-called 'Fly belt.'

Every schoolboy had read about the tsetse-fly in books of travellers and hunters, especially in those by the most famous of them all, David Livingstone the missionary, and out of curiosity I decided to find out what happened when an animal was bitten by the fly, or, as it was termed, fly-struck.

Natives were therefore sent with cattle and dogs into this 'fly country,' with orders to form a camp and expose the animals to the bites of the fly. This was done and it was with great surprise that on their return to the hill the blood of these fly-struck animals was found to contain the same parasite as that found in the nagana cattle.

Nagana and tsetse-fly disease were finally proved to be identical. The tsetse-fly disease was shown to be caused, not, as had been believed, by the poisonous bite of the fly, but by the transference of a protozoal parasite from the fly to the animal in the act of sucking blood.

Now the question arose as to where the fly found the parasite. As the tsetse-flies constantly lived among and fed on wild game, such as buffalo and antelope, these animals were suspected. Their blood was examined,

and before long it became evident that the wild animals acted as the reservoir of the disease, the trypanosomes living in their blood as harmless parasites. When the tsetse-fly fed on blood containing the trypanosome it became infected, and was capable by its bite of giving rise to a fatal disease in cattle, horses, or dogs; whereas if it fed on a wild animal nothing happened, as the wild game are immune to the disease, much in the same way as the goat is immune to Malta fever.

Now that the natural history of the disease had been so far worked out it was evident that its prevention might be attempted.

This can be done in any of three ways: by getting rid of the wild game, the reservoir; or by getting rid of the fly, the vector or carrier; or, lastly, by removing the cattle, horses, and dogs to a safe distance from the 'fly country.'

This work on nagana led later, in 1903, to the discovery of the cause and mode of prevention of sleeping sickness.

Sleeping Sickness.

About the beginning of the century an epidemic of this disease raged round the shores of Lake Victoria in Central Africa. It had been introduced into Uganda from the West Coast, where it had been known for many years as a curious and unaccountable disease. It was observed that although the disease spread in a West African village from man to man apparently by contact, no such thing occurred among natives exiled from their homes. The disease never spread if introduced into native compounds in the West Indies or America, however closely the slaves might be herded together.

The disease remained shrouded in mystery and nothing had been done in the way of prevention, until the matter was taken up by the Royal Society of London in 1902 and a Commission sent out to investigate.

It is not necessary to go into details; suffice it to say that after one or two false starts the Commission in 1903 came to the conclusion that the disease was caused, as in nagana, by a species of trypanosome.

The question of the distribution of sleeping sickness in Uganda was then taken up. This disclosed the remarkable fact that the disease was restricted to the numerous islands in the northern part of the lake and to a narrow belt of country skirting the shores of the lake. In no part of Uganda were cases found more than a few miles from the lake shore.

The next important step in the working out of the etiology was made when it was shown that the distribution of the disease was identical with

the distribution of the common tsetse-fly of the country, *Glossina palpalis*. Where there was no fly there was no sleeping sickness.

The problem was now solved. The epidemic could be stopped either by getting rid of the fly or by removing the natives out of the fly area. As the destruction of the fly was impracticable under the circumstances, the second method was decided on. The natives were moved from the islands and lake shore and placed on healthy inland sites, and the epidemic, which had cost the Protectorate some 200,000 lives, speedily came to an end.

This method of preventing disease, by removing man out of the zone of danger, is an extravagant one, and can only be done in exceptional circumstances. In Uganda the native population could be easily moved, but it meant that from about 1910 until the present day some of the most fertile land in Uganda has been lying derelict, has returned to the primitive jungle. The war delayed things, of course, but it is only now that the natives are being returned to their old homes on the islands and lake shore, in the hope that the fly by this time has lost its infectivity.

The other method, by the destruction of the tsetse-fly, has been carried out successfully in other places. For example, in the island of Principe, off the West Coast of Africa, by destroying the wild animals which supplied a large part of the food of the fly and by clearing the jungle the tsetse-flies disappeared, and with them the disease.

This is the method employed in malaria and yellow fever. It was by destroying the mosquito carrier that Gorgas drove yellow fever out of Havana and, later, both malaria and yellow fever from the Panama Canal Zone.

Thus through the work of Manson, Laveran, Ross, Reed, and others has it been made possible to deal with these two scourges of the tropics, malaria and yellow fever.

I include yellow fever among the protozoal diseases, although Noguchi in 1919 brought forward strong evidence that it is caused by a spirochæte.

In regard to yellow fever the victory has been almost won. During the last century this disease, known as 'yellow jack,' devastated the West Indies and Central and South America.

At the present time, thanks chiefly to the unremitting efforts of the late General Gorgas and the International Health Board of the Rockefeller Foundation, the disease has been driven out of the West Indies and Central America, and only retains a precarious foothold in Colombia and Brazil, whence it will doubtless be ejected during the next year or two.

One of the best examples of the prevention of disease is the attack made on yellow fever in Rio de Janeiro, the capital of Brazil, by the well-known scientist, Dr. Oswaldo Cruz, with the result that the annual deaths in the city from yellow fever fell from 984 in 1902 to 0 in 1909. This brilliant result was brought about by the destruction of the Stegomyia mosquito, the intermediate insect host in yellow fever.

So also in the case of malaria. A dozen years ago, based on the experience gained by Ross on the West Coast of Africa and Ismailia and by Watson in the Federated Malay States, the method of prevention by mosquito control and drainage has been so perfected that the practical blotting out of malaria from a given locality is now merely a matter of expense. A great deal of work has been done during the last few years in the way of experiment in the United States, and Vincent, the President of the Rockefeller Foundation, lately stated that there is evidence that 'under normal conditions an average community can practically rid itself of malaria at a *per capita* cost of from 45 cents to $1 per year.'

This is an altogether inadequate account of the methods of preventing these highly important protozoal diseases. From the few examples given it will be seen that they are most rampant in warm climates, that they are as a rule conveyed from the sick to the healthy by an insect intermediary, and that it is by an attack on this insect, be it mosquito, tsetse-fly, or tick, that the best chance of success in prevention lies.

INFECTIOUS DISEASES.—(C) UNDETERMINED GROUP.

In addition to the bacterial and protozoal infectious diseases, there is a third and large class, known as the 'undetermined group,' in which the parasite is either unknown or doubtful. Many of these undetermined diseases are very common and familiar, such as influenza, measles, scarlet fever, smallpox, typhus fever, trench fever, dengue fever, and sand-fly fever; among animals, rabies, rinderpest, foot-and-mouth disease, and African horse-sickness.

The theory generally held at present in regard to most diseases included in this group is that the living germs causing them are ultra-microscopical, in at least some part of their life history, and this is strengthened by the fact that many of them pass through porcelain filters, which keep back the smallest of the visible bacteria. Hence the name, 'filter-passers.'

Many of these undetermined diseases are highly infectious and appear to infect at a distance through the air, as, for example, in influenza, scarlet fever, and smallpox.

In some of them there is no attempt made at prevention, except that the sick are isolated and placed under quarantine for a longer or shorter period. But in others there are well-known methods of prevention even when the virus is quite unknown. The best example is smallpox, the ravages of which have been completely held in check since the memorable discovery of Jenner. As has already been argued, this method of prevention, by inducing a mild or attenuated form of the disease, is at best a clumsy one, and when the natural history of the smallpox virus is better known it may be hoped that a more fundamental method of preventing this disease may be discovered. In the meantime the best means at our disposal is by the use of vaccine lymph, and people should recognise their responsibility to the community if through ignorance or selfishness they refuse to have their children vaccinated.

Another well-known disease with an unknown virus, rabies or hydrophobia, has also, by the genius and intuition of Pasteur, been robbed of many of its terrors. The mortality following bites of rabid animals has fallen from 16 per cent. to less than 1 per cent.

But in rabies, when the conditions are favourable, the radical method is to drive the disease altogether out of the country by the careful administration of muzzling and quarantine laws. This was carried out successfully in England at the beginning of the century.

Trench Fever.

There are among the diseases of undetermined origin a few which are slowly emerging from the unknown into the known. One of the most interesting of these is trench fever, which came into great prominence during the war.

The history of the investigation of this fever is interesting, and well illustrates the method of studying a disease with a view to its prevention.

Before the war, trench fever was unknown, though there is some evidence that it had been recognised at an earlier date in Poland and called Wolhynia fever. Be that as it may, it is quite certain that, though it was unknown on the Western Front at the beginning of the war, it is no exaggeration to say that it became one of the most powerful factors in reducing our man-power, probably more than a million cases occurring among the Allies on the Western Front. In 1917 in the Second British Army alone, out of a total of 106,000 admissions to hospital at least 20,000 of the cases were trench fever.

Although this fever has well-marked characteristics of its own, such as a peculiar type of temperature curve, and other symptoms, yet for a long time it was unrecognised as a separate entity, and remained mixed up with other diseases, such as typhoid fever, malaria, and rheumatism.

In 1916, MacNee, Renshaw, and Brunt in France made the first definite advance by showing that the blood of trench-fever cases was infective. They succeeded in transferring the disease to healthy men by the injection of the blood. The most careful microscopic examination of the blood corpuscles and lymph failed, however, to reveal any living germ.

Nothing more was done until the following year, when the British War Office took the matter up seriously and formed a Committee for the purpose of investigating the disease.

The United States of America, on coming into the war, at once recognised the importance of trench fever, and without delay also undertook its investigation.

In October 1917, at the first meeting of the Medical Research Committee of the American Red Cross in Paris, Major R. P. Strong recommended that a research into trench fever should be undertaken. He stated that, after several months' study of the problems relating to the prevention of infectious diseases occurring in the Allied Armies on the Western Front, it became evident that the subject of the method of transmission of trench fever was one of the most important for investigation in connection with the loss of man-power in the fighting forces.

At the next meeting, in November 1917, this was agreed to, and a Trench Fever Committee, under the chairmanship of Major Strong, was formed. The research was organised, and experiments begun on February 4, 1918. In less than six months the investigation was completed and the report in the hands of the printer. This is a striking example of research work which, if carried out at the beginning of the war instead of at the end, might have saved the Allied Armies hundreds of thousands of cases of disease, which, although never fatal, were often of long duration and led to much invaliding.

The most important result of the work of these two Committees was that it was amply proved that the louse, and the louse alone, was responsible for the spreading of the disease. This discovery meant that in a short time trench fever would have disappeared from our armies on the Western Front.

Just as the elimination of goat's milk blotted out Malta fever, the elimination of the mosquito malaria and yellow fever, so would the elimination of the louse have completely blotted out trench fever.

This method of prevention, by the destruction of the louse, although doubtless requiring careful organisation and energy in carrying out, was shown before the end of the war to be a perfectly practicable proposition, and there can be little doubt that, if the war had lasted much longer, trench fever, like tetanus, would have practically disappeared.

Besides the main discovery from the preventive point of view that the louse is the carrier, there are many other points of interest in the natural history of trench fever.

The living germ causing it has never been recognised in the human blood or tissues, probably on account of its extreme minuteness, and its consequent liability to confusion with other small granules.

But when the louse sucks blood from a trench-fever case there is apparently a great multiplication and development of the supposed micro-organism. In five to nine days the louse becomes infective, and there is seen in the stomach and intestines enormous numbers of very minute bodies. What the exact nature of these bodies is, is unknown, but there can be little doubt that they are the infecting agents by which the louse passes on the disease. They pass out in countless numbers in the droppings or excreta of the louse, and it is to these bodies in the excreta that infection is due. The louse seldom if ever gives rise to the disease in the act of biting. It is the infective excreta thrown out on the skin which causes the infection. The micro-organisms or so-called Rickettsia bodies contained in the excreta find their way into the blood through abrasions or scratches, and so give rise to the fever.

From what has been said it will be seen that trench fever is an interesting disease. It also explains why it disappears in times of peace. As soon as the war was ended, and our men could leave the trenches and resume their normal habits, the disease disappeared. The louse was eliminated and the trench fever with it.

Typhus Fever.

Another disease of the undetermined group closely related to trench fever and also carried by the louse is typhus fever, one more of the furies following on the heels of war. The French and British Armies escaped this scourge to a great extent, but some of the other countries, such as Serbia, Bulgaria, and Poland, were not so fortunate. It is stated that 120,000 Serbians died of this disease during the war, and it was only after vigorous steps had been taken in sanitary measures directed against the louse that the epidemic was got in hand.

After the long, exhausting Napoleonic wars, with the resulting poverty and destitution, typhus fever was prevalent in Great Britain and Ireland. About the middle of the century the improved economic conditions gradually led to the disappearance of the disease in Britain, although cases still occur in some parts of Ireland.

It is to Nicolle that we owe the advancement in our knowledge of this important disease. His work in Tunis on this subject dates from 1909. He showed that the blood of typhus cases is infective to monkeys, and, most important of all, that the infection takes place through the body louse. Just as in trench fever, the louse becomes infective after some five days, and it has been shown by the late Arthur Bacot of the Lister Institute that the excreta is also infective.

The minute bodies found in the typhus louse are, subject to some differences, very similar to those found in the trench-fever louse and have been named *Rickettsia prowazeki* by Rocha Lima. What group these bodies belong to is still a matter of discussion. Some consider them to be protozoa, with an ultra-microscopical stage in man and a developmental stage in the louse, while others look on them as minute forms of bacteria.

Although there is still some doubt as to the pathological significance of these Rickettsia bodies, the work of Sargent, Rocha Lima, Arkwright and Bacot, Wolbach, Todd and Palfrey has done much to establish a causal relationship between them and these two diseases, typhus and trench fever.

From the point of view of prevention, the important fact is that the infection is carried by the louse, and in the next great war it will be almost as necessary to prepare means for the destruction of the lice as of the enemy.

Rocky Mountain Fever.

A third disease belonging to this interesting little group—Rocky Mountain fever—occurs in certain localities in the United States. It provides another instance of a virus transmitted by an invertebrate host to man. As the result of the work of Ricketts and of Wolbach the wood-tick, *Dermocentor venustus*, is now recognised as the vector. Rickettsia bodies closely resembling those found in association with typhus and trench-fever virus have been shown to be present in the stomach and tissues of the tick, and the same bodies have also been demonstrated in the tissues of infected guinea-pigs.

Another interesting disease of the undetermined group is sand-fly fever, the virus of which is conveyed from man to man by the sand-fly. A

new era in its study has been opened up by the work of Whittingham and Rook, who have learned how to handle, breed, and keep sand-flies in captivity, and have shown that the virus is transmitted from generation to generation of flies without intervening passage through man or other higher animal. The knowledge of the life history of the flies will no doubt lead in due course to the suppression of the disease.

Another type of invertebrate vector is the Kedani mite, *Trombicula akamushi*, which transmits the virus of Japanese river-fever to man from wild animals. The dangerous character of this disease (Tsutsugamushi) and the minute size of the mite together have presented great difficulties to the Japanese investigators. Protection from the mite by special clothing and bathing after exposure to risk of infection are at present the most hopeful methods of prophylaxis.

Antitoxic sera have also been used with some measure of success in the prevention of diseases of this group. Degkwitz and others in Germany are reported to have been very successful in protecting children from measles and scarlet fever by injecting them with a small quantity of serum from convalescent patients. This method has also been found very useful under suitable conditions to protect cattle from foot-and-mouth disease.

But far more hopeful than protection by serum alone is the use of a vaccine to produce a lasting immunity, combined with antitoxin to prevent the vaccine from producing unpleasant results—the so-called toxin-antitoxin method. Most of the diseases for which this method of prophylaxis has proved valuable have been diseases of animals, such as pleuro-pneumonia of cattle, rinderpest, and foot-and-mouth disease; but quite recently the method of Dick, of Chicago, in scarlet fever has been supported by a number of observations. The system of testing and producing immunity is planned on the same lines as the Schick method for diphtheria.

DIETETIC DEFICIENCIES.—DEFICIENCY DISEASES.

The preceding account is but a short and meagre history of the marvellous advance which has been made in the prevention of infectious diseases in our times, an advance due in great part to the work of two men, Pasteur the Frenchman and Koch the German; those who have come after them have merely followed in their footsteps, been their disciples.

Time will not permit even to touch upon the advances made in the prevention of other important diseases, such as the surgical infections and

those caused by intestinal parasites, prominent among which are the hookworms and bilharzia.

This advance has not been limited to the infectious group: it has been shared by other groups, notably those due to dietetic deficiencies, the so-called deficiency diseases. These deficiency diseases are just as important, or even more important, than the infectious, since they are always with us and exact an enormous toll in lowered health, lowered vitality, malformation, and inefficiency.

Until a few years ago it was taught in the schools that a complete diet consisted of certain proportions of proteins, carbohydrates, fats, and salts. But our knowledge is constantly increasing, our ideas about things constantly changing, and what is looked on to-day as absolute immutable truth to-morrow is seen in the light of some newer knowledge to be but a crude beginning. So the teaching concerning what constitutes a complete and healthy diet has changed, inasmuch as certain substances have been discovered in food-stuffs in the absence of which an adequate number of calories supplied in the form of proteins, carbohydrates, fats, and salts can alone neither promote growth nor support life indefinitely. These accessory food factors, or vitamins as they have been named, are present in such minute quantities in foods that they have never been isolated, and their chemical composition is therefore unknown. It is still a matter of opinion as to whether they really constitute parts of the structure of living tissues, or whether they merely act as catalysts or stimulators in the processes of growth and metabolism. That they are definite chemical substances which can be added to or removed from a food-stuff, with good or evil results, has, however, been abundantly proved.

The untutored savage living on the natural fruits of the earth and the chase knows no deficiency diseases. It is only when man begins by artificial means to polish his rice, whiten his flour, and tin his beef and vegetables that the trouble begins. Civilised man living in comfort, drawing his food supply from the whole earth and able to vary his dietary at will, is in little danger; but it is otherwise with children and adults living under institutional conditions, with armies on active service, encountering extremes of climate, and with young infants on their naturally restricted diet. While it is true that deficiency diseases will only develop to their well-marked dangerous stage if the deficiency of accessory factor is severe and protracted, a slighter deficiency, if prolonged, may cause a condition of general ill-health and inefficiency not less important although ill defined and difficult to diagnose. This fact is of special importance in the case of infants and young children.

The Discovery of Vitamins.

At the present time, three, and possibly four, distinct vitamins have been described and studied, and it is probably only a matter of time for others to be discovered.

The discovery of vitamins dates to the middle of the 18th century. In 1747, James Lind, a surgeon in the British Navy, carried out a series of experimental observations upon sailors suffering from scurvy, the conception and performance of which were entirely admirable. By appropriate control experiments he showed that the medical means in vogue for the treatment of the disease were futile, when not harmful, but that orange and lemon juices were a specific cure. Lind attempted to ascertain the relative anti-scorbutic value of various fruits and green vegetables, but was unable to observe a 'superior virtue' in one rather than in another. He confirmed Kramer's observations made at the beginning of the 18th century, during the war between the Turks and the Holy Roman Empire, that dried vegetables were useless, and adopts the explanation of his friend Cockburn 'that no moisture whatever could restore the natural juices of the plant lost by evaporation,' which Cockburn imagined were 'altered by a fermentation which they underwent in drying.'

Lind was struck with the beneficial effect of cow's milk in the treatment of scurvy. He explained it on the supposition of the milk 'being a truly vegetable liquor, an emulsion prepared of the most succulent wholesome herbs.'

Lind applied himself to the applications of these discoveries for the prevention of scurvy in the Navy, and recommended lemon-juice concentrated to a syrup by evaporation to be carried in all ships and served out to the sailors.

By the beginning of the 19th century the carriage of lemon-juice was made compulsory, first in the Navy and subsequently in the mercantile marine, with the result that the ravages of scurvy were prevented. With the advent of steam traction, too, the length of voyages was curtailed and supplies of fresh provisions were obtained at more frequent intervals. Scurvy became rare, and the medical profession, being no longer faced with this disease of dietary deficiency, soon forgot the significance of Lind's discoveries.

Before leaving this subject a curious fact may be related. The lemon-juice supplied to the Navy was at first made from lemons grown in Spain and the Mediterranean countries. Afterwards, when England took over

the West Indies, it was made from the lime, and scurvy again broke out. The reason of this is now known to be that, whereas the lemon is particularly rich in anti-scorbutic vitamin, the lime is correspondingly poor.

The scientific study of the disease may be said to have lapsed for a century and a half, until Holst and his co-workers in Copenhagen investigated the etiology of scurvy anew on modern lines, with the help of experiments on animals. Their work, published in 1907 and 1912, formed the basis for the numerous researches carried out in England and America during and since the recent war. As a result of this work the etiology of scurvy, discovered in effect centuries earlier, has been firmly established as due to lack of a specific, undetermined, and as yet unisolated, constituent of fresh foods, especially of fresh vegetables and fruits, now known as Vitamin C.

In the meantime the existence of a second vitamin, the so-called anti-beri-beri, or anti-neuritic vitamin, Vitamin B, had been discovered. Eijkman's admirable studies at the end of last century, in 1897, on the etiology of beri-beri in the Dutch Indies brought forward evidence for the view that this disease was of dietetic origin, and was caused by a diet consisting too exclusively of highly milled and polished rice. He showed that the disease could be prevented if the outer layer (or pericarp) and the embryo of the seed, which had been removed in the process of milling, were restored to the 'polished' rice. Eijkman's discovery of the analogous disease in birds, *Polyneuritis gallinarum*, provided the necessary tool for further investigation of the subject. The researches of Grijns and others showed that the bran and polishings of rice were only one of many rich natural sources of the unknown principle preventing beri-beri, and it became evident that, while the disease is usually confined to tropical races subsisting largely on rice, the European white-bread eater is protected only by the varied diet he usually enjoys. Experience on active service shows that beri-beri may really develop on a diet of tinned meat and white bread or biscuit.

During the late war two examples of the use made of this new knowledge occurred in Mesopotamia. At the beginning of the campaign, on account of a difficulty in transport, there was a shortage of fresh food, with the curious result that scurvy broke out among the Indian troops and beri-beri among the British. The Indians were living on dried pulses, such as peas, beans, and lentils; the British on tinned beef and biscuits. The former diet was deficient in the anti-scorbutic vitamin on account of the complete drying of the seeds; the latter in the anti-beri-beri factor on account of the use of white flour from which the germ had been removed.

Some years ago it had been discovered that if dried seeds are germinated, a quantity of the anti-scorbutic vitamin is produced by the act of sprouting. This was done. The dried peas and beans were soaked in water and then spread out in shallow layers, to cause them to sprout, which they readily did in the warm climate. The germinated seeds were then issued to the Indian troops and cooked in the usual way. As a result of this simple procedure the scurvy completely disappeared.

In regard to the British troops it was known that the anti-beri-beri vitamin is contained in large quantities in certain cells, and notably in yeast cells. A small quantity of this substance in the form of marmite was added to the soldier's diet of bully-beef and biscuits, and the beri-beri in like manner disappeared.

It may seem strange that the conception of the rôle of vitamins in nutrition should have come first from the pathologist, and should not have emerged from the important advances in our knowledge of the physiology of nutrition which were made during the second half of the last century. The physiologists were preoccupied with the chemical composition of food-stuffs and their value for supplying energy and supporting growth, and with the necessity for supplying the requisite number of calories in a diet, distributed appropriately among proteins, fats, and carbohydrates, with adequate selection of mineral salts. It was only when these researches led to experiments in which animals were fed upon various mixtures of purified food elements that the investigators in this field began to realise that their repeated failures to rear animals upon such carefully arranged diets were not due to accident. The truth was suspected by Lunin in 1881, but it was not until 1912 that Hopkins published the classic experiments which proved the fact beyond a doubt. In the course of work along the same lines in the United States, McCollum and Davis in 1915 rediscovered Vitamin B, and, in addition, a third essential dietary constituent, a fat-soluble vitamin, present in butter-fat and certain other fats of animal origin, especially in cod-liver oil and other fish oils. This vitamin is known as fat-soluble Vitamin A.

Rickets as a Deficiency Disease.

The discovery of the fat-soluble vitamins proved to be of great importance in elucidating the etiology of this disease, which had for long been an unsolved problem. Some authorities had erroneously considered it to be an infectious disease, like tuberculosis. Another school held the so-called Domestication Theory, that it was caused by unnatural surroundings, involving a want of sunlight, fresh air, and exercise. A third considered

rickets to be caused by improper feeding, though opinions differed as to the exact nature of the dietetic defect. The conclusion, first put forward by Mellanby in 1918, that a deficiency of fat-soluble vitamins plays a most important part in the causation of the disease is now generally accepted. This has been established by a large amount of work, both experimental and clinical, carried out by Mellanby himself, McCollum and Hess and their respective co-workers in the United States, and Korenchevsky and others in England. It may be laid down that if a young animal is supplied with a sufficiency of these vitamins, rickets will not develop. The question of prevention is therefore one of economics. The difficulty is that these fat-soluble vitamins are chiefly found in such food-stuffs as butter, eggs, the fat of beef and mutton, and fish oils, all expensive articles of diet which the poorer classes can seldom afford. The only 'butter' used by them is probably some form of margarine, made from vegetable oils which contain little or no anti-rachitic vitamin. The question of prevention is for the sociologist. Science can only discover the causes and point the means. It is for governments and local authorities to carry out preventive measures in practice, and it is to be feared that science is often far ahead of the community in its share of the work.

Although the theory that rickets is an infectious disease has been exploded, a great and remarkable truth was contained in the domestication and hygienic theories which held that, among other unhygienic conditions, want of sunlight was concerned in the etiology of the disease. During the last five years it has been discovered that exposure to sunlight or to the ultra-violet rays of the mercury vapour quartz lamp can cure rickets in children. Experiments on animals have shown that the effective rays in the sunlight are also the ultra-violet. This discovery has indicated lack of sunlight during winter as one factor concerned in the large spring incidence of the disease in industrial cities in northern climates.

A complete and well-controlled research showing the interaction of diet and light in the prevention and cure of rickets in infants was gained in Vienna, since the war, by Dr. Harriette Chick of the Lister Institute and her four colleagues. There the curious fact came to light that infants fed on a diet deficient in anti-rachitic vitamin developed the disease only in winter and not in summer, and, moreover, could be cured in winter by exposure to artificial forms of radiation or by administration of cod-liver oil without any other change in diet or management. Another set of children who had a sufficient supply of fat-soluble vitamins in their diet, in the form of cod-liver oil, escaped the disease altogether.

Experiments on rats have also shown that in animals fed on a rickets-producing diet, rickets does not occur if the rats are exposed regularly to sunlight or to the rays of the mercury lamp, or other form of artificial ultra-violet radiation; whereas, if they are kept in the dark, rickets does develop. If, on the other hand, the diet is complete in all respects, including abundance of fat-soluble vitamins, the animals do not develop the disease, even if kept constantly in the dark.

How this is brought about is not known. At one time it was thought that the action of the ultra-violet rays on the tissues might enable the animal to synthesise fat-soluble vitamins, as it does in the tissues of plants, but recent evidence brought forward by Miss Margaret Hume in Vienna, and by Goldblatt and Soames at the Lister Institute, suggests that light can neither create nor act as a substitute for the vitamin. It seems rather to act as a stimulant, enabling the animal to make full and economical use of its store of fat-soluble vitamins, and when the store is used up growth ceases in spite of the continued action of the rays.

An important and practical point in regard to the connection between diet and sunlight and the formation of the anti-rachitic vitamin is the relation to cow's milk. Recent work carried out by Dr. Ethel Luce at the Lister Institute has shown that milk obtained from a cow on pasture in summer contains a sufficiency of the growth-promoting and anti-rachitic fat-soluble vitamins. In winter, on the other hand, if the cow is stall-fed and kept in a dark stable, the milk may become deficient in these respects and young animals fed on it may become rachitic. This work shows that the seasonal variation in quality of the cow's milk may be an additional factor in the seasonal incidence of infants reared upon it. It also disposes of the idea, very current in some quarters, that cow's milk possesses low and negligible anti-rachitic properties and that the anti-rachitic properties of cod-liver oil are specific and peculiar to that substance.

Enough has been said to show that rickets may be regarded as a disease of sunless houses combined with a diet deficient in the anti-rachitic vitamin, and the means of prevention are sufficiently obvious, if not always easy and simple to carry out.

Doubtless in the future this new knowledge in regard to the accessory food factors in diet will be used to a greater extent than it has been up to the present, in which case it is not too much to expect that the city children of some future generation will have better-grown bodies and stronger, healthier teeth than their predecessors of the pre-vitamin age.

This might be attained in a comparatively near future if only man could be allowed to work out his salvation in peace. Instead of this, great wars come and throw back the work for generations.

To saddle the country with a million and a half of unemployed, with the consequent poverty, insufficient food, clothing and housing, is not calculated to further the prevention of disease and raise the standard of health. Is it too much to hope that in the revolving years a time may come when by a Confederation or League of Nations the world may be so policed that no one country will be able with impunity to attempt the destruction of its neighbour? Until this happens it is difficult to see how rickets, tuberculosis, and other diseases can be adequately dealt with in our city populations.

DISEASES DUE TO DUCTLESS GLANDS.

I can only briefly allude to the astonishing advance in our knowledge of the diseases caused by a defect or excess of secretion of the ductless glands. Many of these discoveries are among the fairy tales of science.

All this advance has taken place in the comparatively short space of time under review.

Professor Starling, one of the chief protagonists in this advance, in his Harveian Oration a year ago states this very vividly: 'When I compare our present knowledge of the workings of the body, and our powers of interfering with and of controlling those workings for the benefit of humanity, with the ignorance and despairing impotence of my student days, I feel that I have had the good fortune to see the sun rise on a darkened world, and that the life of my contemporaries has coincided not with a renaissance but with a new birth of man's powers over his environment and his destinies, unparalleled in the whole history of mankind. Not but there is still much to be learned: the ocean of the unknown still stretches far and wide in front of us, but for its exploration we have the light of day to guide us; we know the directions in which we would sail, and every day, by the co-operation of all branches of science, our means of conveyance are becoming more swift and sure. Only labour is required to extend almost without limit our understanding of the human body and our control of its fate.'

There is one point of likeness between the vitamins which we have been considering and these glandular secretions, or hormones, as they are named. Just as we have seen that the presence or absence of an extremely minute

quantity of a vitamin may determine growth and health or disease and death, so an extremely minute quantity of glandular secretion may have a similar effect.

The anterior lobe of the pituitary gland is a very small body, yet an excess of its secretion will cause a child to grow into a giant; a deficiency, and the growing child will remain an infant.

The best known of the ductless glands is the thyroid, and the effect of its secretion is truly marvellous. A deficiency, and the child grows up a heavy-featured, gibbering idiot. Rectify the supply of thyroid secretion: the heavy features disappear, the eyes brighten, the intelligence returns, and instead of the former heavy-jowled imbecile you have a bright, happy and normal schoolboy.

On the other hand, if there is an excess of the thyroid hormone, exophthalmic goitre, or Graves's disease, is the result. Remove the redundancy and health returns.

The active principle of the thyroid has lately been shown to be a compound containing iodine. If there is no iodine in the soil or water, goitre is the result, as in parts of Switzerland, Canada, and the United States. This aspect of the subject was taken up some ten years ago by Dr. David Marine and his colleagues at Cleveland, Ohio. They find that endemic goitre may be prevented by the simple method of giving for a time minute doses of iodine, and conclude that with this simple, rational, and cheap means of prevention, this human scourge, which has taken its toll in misery, suffering, and death throughout all ages, can and should be controlled, if not eliminated, and look forward in imagination, a few generations hence, to the final closing of the chapter on endemic goitre and cretinism in every civilised nation in the world.

Many advances have also been made in our knowledge of the function and uses of other ductless glands, and, as you know, the latest victory in this field is the discovery of insulin and the successful treatment of severe diabetes, for which magnificent work your own townsmen Banting and Best deserve the highest honour.

In many other directions than those touched upon has there been progress in the prevention of disease. It would take more than one address to describe the activities of the Rockefeller Foundation alone. Campaigns for the relief and control of hookworm disease, malaria control, the eradication of yellow fever, anti-tuberculosis work and education are being pursued on such a scale and at such a lavish expenditure of money as to leave us in the Old Country breathless with admiration and envy.

This foundation, incorporated in 1913, was founded, in the words of the President, 'to stimulate world-wide research, to aid the diffusion of knowledge, to encourage co-operation in medical education and public health.' Its chartered purpose is to promote, not the exclusive prosperity of any one nation, but 'the well-being of mankind throughout the world.'

Science, indeed, knows no boundaries of nations, languages, or creeds. It is truly international. We are all children of one Father. The advance of knowledge in the causation and prevention of disease is not for the benefit of any one country, but for all—for the lonely African native, deserted by his tribe, dying in the jungle of sleeping sickness, or the Indian or Chinese coolie dying miserably of beri-beri, just as much as for the citizens of our own towns.

From what has been said it is abundantly clear that during the comparatively few years that have passed since this Association first met in Canada, enormous advances have been made in the prevention of disease. Before that time we were still in the gloom and shadow of the dark ages. Now we have come out into the light. Man has come into his heritage and seems now to possess some particle of the universal creative force in virtue of which he can wrest from Nature the secrets so jealously guarded by her and bend them to his own desire.

But let there be no mistake, much has been done but much more remains to be done. Mankind is still groaning and travailing under a grievous burden and weight of pain, sickness, and disease. Interruptions are sure to come in the future as they have in the past in the work of removing the incubus, but, in spite of these, it is the duty of science to go steadily forward, illuminating the dark places in hope of happier times.

SECTION A.—MATHEMATICAL AND PHYSICAL SCIENCE.

THE ANALYSIS OF CRYSTAL STRUCTURE BY X-RAYS.

ADDRESS BY

Professor Sir W. H. BRAGG, K.B.E., D.Sc., F.R.S.,

PRESIDENT OF THE SECTION.

In this address I propose to consider the new methods of analysing the structure of materials by means of X-rays, considering especially the stages by which they move towards their objective. It is convenient to recognise three such stages, of which the first comprises the simplest and most direct measurements and the last the most indirect and complex.

The fundamental measurement of the method is the angle at which rays of a given wave-length are reflected by a set of planes within the crystal. The planes of a 'set' are all exactly like one another: an imaginary observer within the crystal could not tell by any change in his surroundings that he had been moved from one plane to another. Sometimes there is no reflection of the first order from a set so defined, because the planes may be interleaved by other planes so spaced and of such strength as to annul the true reflection; but this can always be allowed for. When the wave-length of the X-rays is known, the angular measurement can be used to find the spacing of the set of planes, and in this way a linear dimension of the crystal is measured. The spacing is the distance between any plane and its nearest like neighbour on either side. If the spacings of three different sets of planes are found, the volume of the unit cell is found. The crystal unit cell is bounded by six faces, each set of planes furnishing a pair. The pair consists of two neighbouring planes of the set. The cell may have a great variety of forms, but has always the same volume. The specific gravity of the substance being known, it is possible to find the number of atoms of various kinds which the cell contains: the proportion of the various kinds is necessarily the same as in the molecule of the substance. The cell is in practice found always to contain a small integral number of molecules, one, two, three, or four, rarely more. This assemblage of molecules is fully representative of the crystal; by the mere repetition of the cell, without the addition of any new features, the crystal with all its properties is produced.

There are, therefore, three types of assemblage. The simplest is that of the single atom, as in helium in the gaseous state, in which the behaviour of every atom is on the whole the same as the behaviour of any other. The next is that of the molecule, the smallest portion of a liquid or gas which has all the properties of the whole: and lastly, the crystal unit, the smallest portion of a crystal (really the simplest form of a solid

substance) which has all the properties of the crystal. There are atoms of silicon and of oxygen: there is a molecule of silicon dioxide, and a crystal unit of quartz containing three molecules of silicon dioxide. The separate atoms of silicon and oxygen are not silicon dioxide, of course: in the same way the molecule of silicon dioxide is not quartz; the crystal unit consisting of three molecules arranged in a particular way *is* quartz.

The final aim of the X-ray analysis of crystals is to determine the arrangement of the atoms and the molecules in the crystal unit, and to account for the properties of the crystal in terms of that arrangement.

The first step is the determination of the dimensions of the crystal unit cell: any one of the possible ways in which the cell can be drawn will do. When this has been completed it is a simple calculation in geometry to find the distance between any atom and any other atom in the crystal of like kind and condition, or, in other words, the distance an observer would have to travel from any point within the crystal to any other point from which the outlook would be exactly the same and would be similarly oriented. This is the only measurement which the X-rays make directly: any other measurement of distance is made indirectly, by aid of some additional physical or chemical reasoning. It is not possible by direct X-ray measurement to determine the distance between any two points—atom centres, for example—within the same cell.

Let us take an example. The crystal unit of naphthalene has the dimensions defined in the usual way by the statement:—

$$a=8.34\text{Å} \quad b=6.05\text{Å} \quad c=8.69\text{Å} \quad \beta=122^\circ\,49' \quad \alpha=\gamma=90^\circ.$$

It contains two molecules: an integral number, as always. These facts are given directly by the X-ray measurements. But there is no direct determination of the distance between any carbon atom and any other carbon atom contained within the same cell: the measurements given are those of the distances between any atom and the nearest neighbours, in three principal directions, which are exactly like itself, these distances being the lengths of the edge of the cell. There is not even a measurement of the distance between the two molecules in the same cell, because they are not similarly oriented. In fact, there is no clear meaning in the term 'distance' in this case, just as we cannot state the distance between an object and its image in a mirror, unless the object is a point of no dimensions. If the molecule of naphthalene has a centre of symmetry, as is indeed indicated during the development of the results of the X-ray analysis, it is possible to state the distance between the centres of symmetry of the two molecules in the same cell, but this does not define the distance between any atom in one of the two molecules and any atom in the other. All such distances, if they are to be defined and measured, can only be found by the aid of fresh considerations.

Or again, let us take the case of rock-salt. The crystal unit cell of rock-salt contains one molecule: one form of the cell has for its eight corners the six middle points of the faces of a certain cube (edge=5.62 A.U.) and two of the opposite ends of any diagonal of the cube. The so-called face-centred cube is four times as large as the cell, and contains four molecules. The dimensions of the cell are determined directly by the X-rays, which

measure the distance between each of the three pairs of parallel faces that contain it. The cell may be placed so that each corner of it is associated in the same way with a molecule of sodium, let us say: and, of course, the knowledge of the dimensions of the cell is equivalent to a knowledge of the distance between any two sodium atoms in the crystal, which atoms are all alike in every respect. But we have no direct measurement by the X-ray methods of the distance between a sodium and a chlorine atom. We infer that the chlorine atom lies at the centre of the sodium cell, or *vice versâ*, from considerations of symmetry. Crystallographic observations of the exterior form of the cell assign to the crystal the fullest symmetry that a crystal can possess. If the cell that has been described is to contain the elements of such full symmetry, the chlorine atom must lie at the centre of it. It cannot lie anywhere else, for every cell would contain a chlorine atom similarly placed. There would then be unique directions in the crystal; that is to say, polarities. Moreover, both the sodium and the chlorine atoms must themselves contain every symmetry of the highest class: the full tale of planes of symmetry, axes of rotation, and so on. They both have centres, and we can state the distance between a chlorine atom and a sodium atom because we can state it as between centre and centre, and put it equal to half the distance between two sodium atoms on either side of the chlorine. The structure of sodium chloride is then determined completely.

It may possibly be a difficulty that the cell so described does not at first appear to have all the symmetries of the rock-salt cube, but it is to be remembered that we are to expect the full display of symmetries only when the cell has been repeated indefinitely in all directions. We may take a simple case, as follows:—

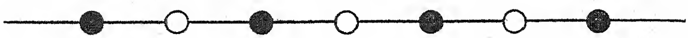


Fig. 1.

Suppose sodium and chlorine atoms were to be arranged in a line as in the figure, just as they are in any of the three principal directions in the crystal. A plane of symmetry perpendicular to the line of atoms indefinitely prolonged may be drawn through the centre of any atom. The unit cell is one molecule: one chlorine and one sodium. The unit by itself has not this symmetry, but the repetition of the same molecule in either direction on either side provides the symmetry. Moreover, each sodium and each chlorine must itself have a plane of symmetry, and the planes are equally spaced. We can state the distance between a sodium and a chlorine atom as half the distance between two sodiums.

Let us take one more instance, the diamond. The crystal unit cell contains two atoms of carbon: as in the case of rock-salt, it may be so chosen that, of its eight corners, six are the middle point of the faces of a certain cube and two are the ends of any diagonal of the cube. The sides of this cell are determined by the X-rays, and are all equal to 2.52 A.U. This is the distance between any carbon atom and the nearest carbon atom which is exactly like itself. The distance between the two carbon atoms in the same cell is not measured directly, but can be inferred after it has

been defined. This we are able to do because the carbon atom is tetrahedral; a tetrahedron has a centre, and we can state the distance between the centres of two tetrahedra, no matter how the tetrahedra are oriented. We know that the carbon atom, as built into the crystal, is tetrahedral, because the X-ray observations show that four trigonal axes meet in it. The two atoms in the cell are oriented differently; one may be said to be the image of the other, if translation shifts are ignored, in each of the faces of the cube. Considerations of symmetry or X-ray observations show that the centre of an atom of the one orientation lies at the centre of a tetrahedron formed by four atoms of the other orientation. The edge of this tetrahedron is the edge of the unit cell, and its length is 2.52 A.U. It may then be calculated that the distance between the one atom and the others, its nearest neighbours, is 1.54 A.U. We may call this distance the diameter of the carbon atom, but we must remember our original definition of the meaning of the term. Thus the 2.52 A.U. is the result of a direct unaided X-ray measurement, but the 1.54 A.U. is not, and has no meaning except after special definition.

Only such distances between atoms as can be calculated from the dimensions of the unit cell can be measured directly and without qualification. The determination of these distances may be looked on as the result of the *first stage* of the analysis by X-rays.

We now come to a *second stage*. It is possible to make other statements of the relative positions of atoms and molecules which, though less complete and informative than those of distances, and their orientations, are necessary to the solution of the crystal structure problem. These also are deduced by means of the X-ray methods.

It often occurs that the atoms or molecules in one cell can be divided into two portions which are the reflections of one another across some plane, or can be brought to be the reflection of each other by a shift parallel to the plane. In that case the orientation of the plane and the amount of the shift can be stated definitely, the former by inspection of the crystal or by X-ray observations, the latter by X-ray observations alone. So also it may happen that the atoms or molecules in the same cell may be divided into portions which can be made to coincide with each other by a rotation round some axis with or without a shift parallel to that axis. The direction of the axis can be found by inspection of the crystal or by X-ray observations; the amount of the shift can be found by X-ray observations alone.

In these cases the distances that are found by the X-ray method are all that can be stated without special definition. It is not possible to state the distance between an object and its image in a mirror, if the object has any extension in space; but it is possible to state the magnitude of a shift. Measurements of this sort constitute a characteristic feature of the X-ray analysis, for which reason I would like to discuss them briefly.

We know that it is possible to separate crystals into thirty-two classes, according to the kind of external symmetry which they display. As we have hitherto been unable to look into the interior of the crystal, we have been obliged to be content with this imperfect classification by outer appearance. It has been shown, however, that there is a classification by inner arrangement which is perfect and includes the other. It is beyond the limits of ordinary vision: out of the range of the lens and the

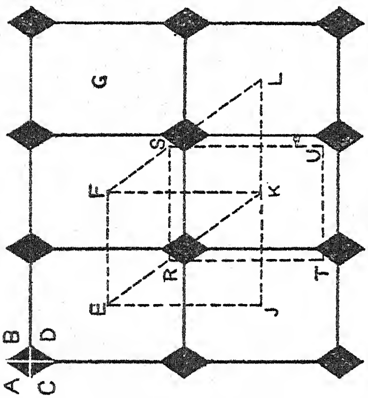


Fig. 2.

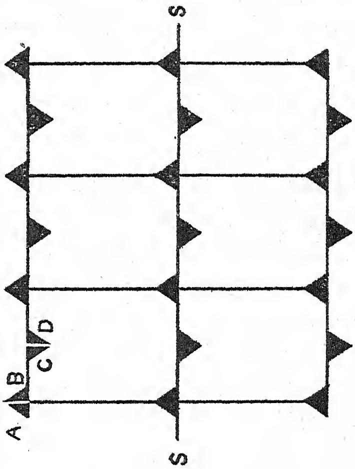


Fig. 3.

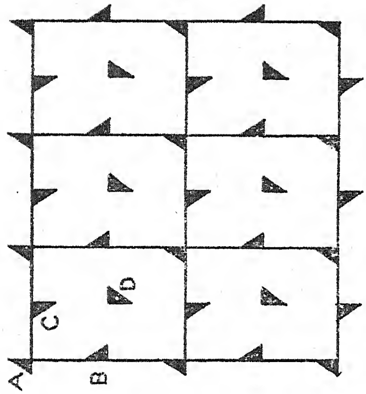


Fig. 4.

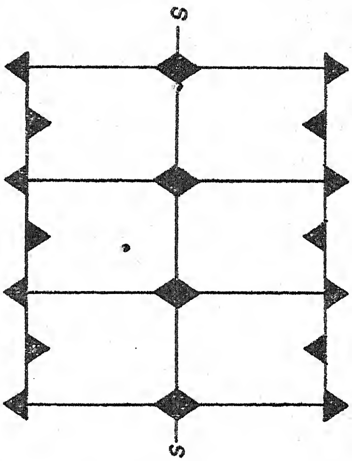


Fig. 3A.

goniometer. The interior arrangements of the crystal, of which the outer form is one consequence, are so varied as to furnish 230 different modes. With very few exceptions the X-rays now allow us to carry the classification to this higher degree. If the modes are grouped according to the external features of the crystals that follow them, we come to the well-known thirty-two classes, there being several modes in every class. I may be permitted to illustrate this important point by examples, although it is familiar to those who have studied crystallography. Let us consider first a two-dimensional example, which is much easier to describe than the three-dimensional actuality, and contains all the essential ideas.

Consider an arrangement of figures in a plane which displays symmetry across two planes at right angles to one another. Such arrangement may be exhibited diagrammatically, as in fig. 2. The unit cell may be drawn in various ways, EFKJ, EFLK, RSUT, and so on. The cell contains, however it is drawn, either a whole diamond or enough parts to make up a whole diamond. Each diamond can be divided into four parts: B and D are the reflections of A and C across a plane; C and D are the reflection of A and B across a plane at right angles to the first plane. Unless the diamond, the content of one cell, could be divided in this way there could not be the double symmetry. But, granted this division into four portions, it is not necessary that the four should be arranged as in the figure in order that the double symmetry may be obtained. There are two alternatives (figs. 3 and 4).

In fig. 3 the lower half of each diamond—that is to say, the portions C and D—are shifted, whether to right or to left is immaterial, by an amount equal to one-half of one side of the cell EFKJ. The symmetry about a vertical line in the plane of the paper is obviously retained. It is not so obvious that there is still any symmetry about the horizontal line until we realise that we mean only 'observable symmetry': that which is to be seen in the outer form of the indefinitely extended figure, corresponding to the crystal. Clearly, the whole figure will present the same appearance from below as from above. In fact, we can see that as a whole the lower part of the figure is symmetrical with the upper part by imagining the upper and the lower to be further shifted relatively as in fig. 3A: the two parts sliding on one another along the line SS. The two parts are then the image of each other across SS in the full sense of the word.

From fig. 2A we may also realise that the amount of the original shift must be equal to one half of EF: no other shift will give the symmetry which fig. 3A shows. In figs. 5 and 5A a different shift has been given, and the failure is clear.

In fig. 4 not only are C and D shifted parallel to the horizontal line, but also B and D are shifted parallel to the vertical; this time the amount of shift is one-half of the side EJ.

The three modes of figs. 2, 3 and 4 all lead to the same external symmetry. There is one more which is based, as we should say, on a different lattice and is symmetrical, like the others, about two lines at right angles to each other. It is shown in fig. 6. There are no variations of fig. 6, as of fig. 2, to be obtained by the introduction of shifts. If in fig. 6 we shift C and D relatively to A and B, as we did in fig. 3A, we find that they can now be described as the direct reflection of A′B′ into CD and of A′C into B′D, and the mode of fig. 6A is the same as that of fig. 6.

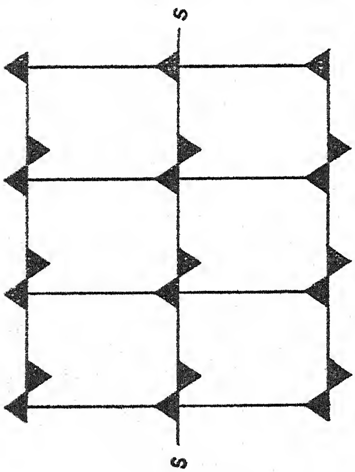


FIG. 5.

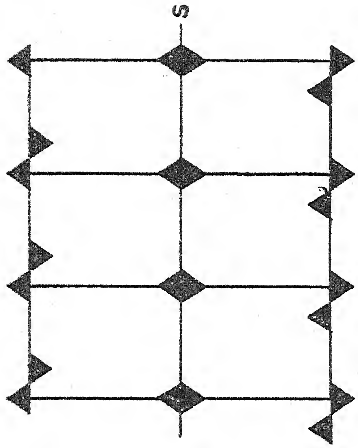


FIG 5A.

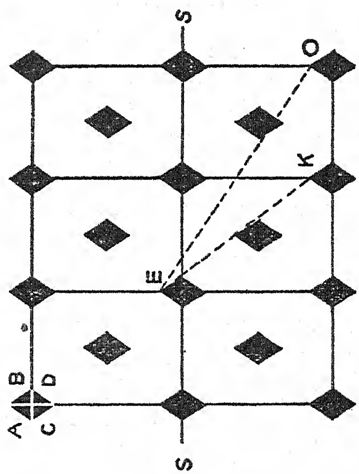


FIG. 6.

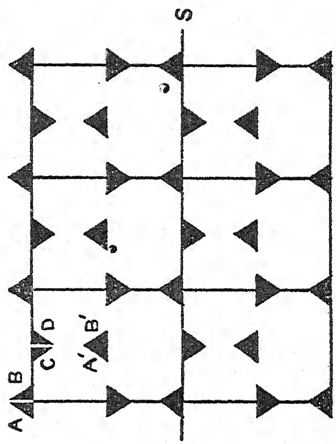
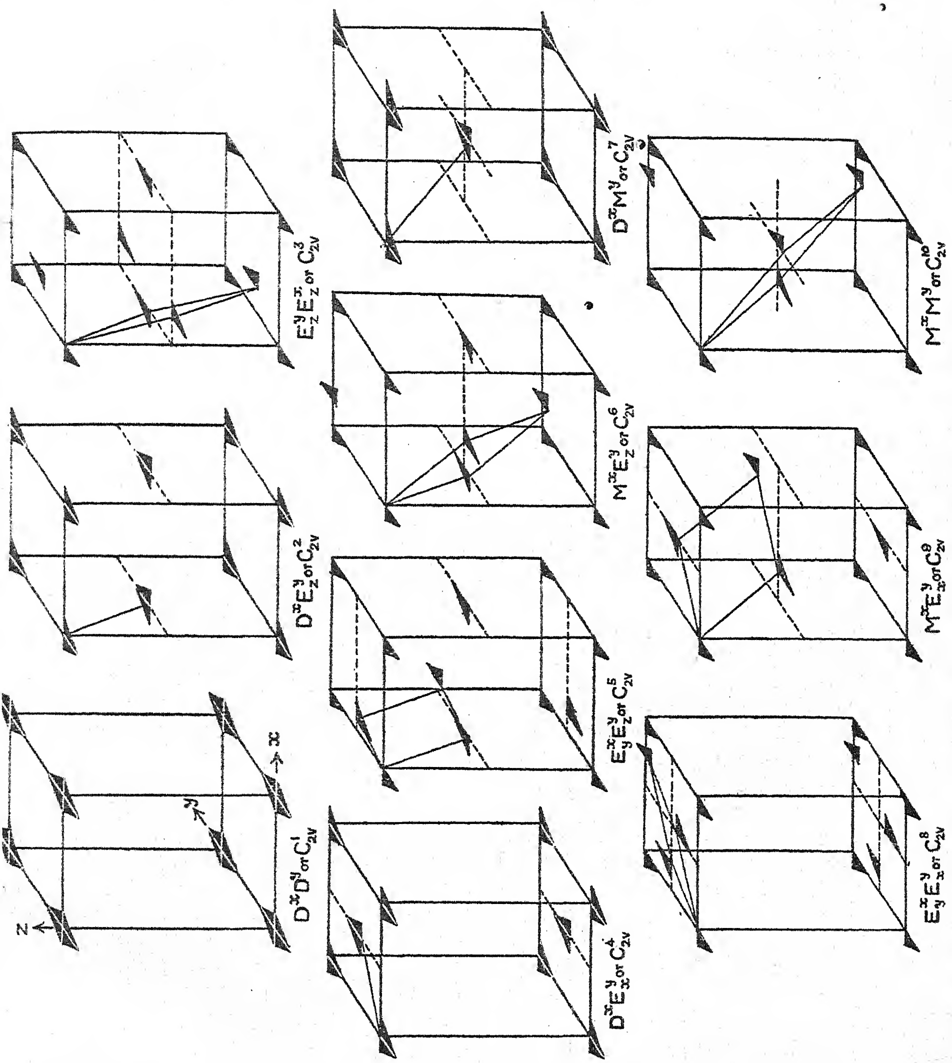


FIG. 6A.

There are therefore four *modes* in one *class*: four varieties of internal arrangement which all lead to the same external appearance of symmetry.

Our example is two-dimensional, and the crystal has three dimensions. But there are no new ideas to be added: it is only the numbers of symmetries, modes, and classes that are increased. If, for example, we continue the study of the modes of arrangement that lead to an external symmetry of reflection across two planes at right angles to each other, we find that there are four lattices instead of two, and twenty-two modes instead of four. The class containing crystals that possesses this particular form of symmetry is generally called the 'hemimorphic class in the orthorhombic system.' Its symbol is C_{2v}: the symbols of the four lattices are Γ_0 Γ_0' Γ_0'' Γ_0'''. In every case the content of the unit cell is divisible into four parts, corresponding to the ABCD of figs. 2 to 6. The ten modes in the Γ_0 lattice are shown in fig. 7, which will serve to show the numerical increase due to the introduction of the third dimension. Under each separate figure is given, beside the crystallographic symbol, another symbol which describes the shifts: D^x means a direct reflection across a plane parallel to yz; E^x_y a reflection across a plane parallel to yz, together with a shift parallel to the axis of y equal to half the y edge of the cell, and M^x a reflection across a plane parallel to yz, together with a shift parallel to the diagonal of the yz face and equal to half that diagonal.

Let us now see how the X-ray analysis distinguishes the mode. Let us imagine that fig. 2 represented a number of pits in a plane reflecting surface. The surface could be used as a grating having many spacings instead of one. If, for example, we so placed it that the horizontal lines of the figure were parallel to the slit of the spectroscope the spacing would be equal to EJ: if the vertical, the spacing would be equal to EF. Again, if the grating were so placed that EK, for example, were vertical, the spacing would be the perpendicular distance between EK and FL. If the surface is pitted as in fig. 3, the spacing when the horizontal line is parallel to the slit is the same as before; but when the vertical is parallel to the slit the effective spacing is only half what it was in fig. 2. This follows from the fact that if we divided the surface into a number of vertical narrow strips the diffracting effect of each such strip, for this position, depends on the total amount of reflecting surface contained in the strip, but not on its distribution along the slip. It does not matter that C and D are upside-down as compared to A and B. The strata consisting of C and D portions have interleaved the strata of A and B portions. This halving of a spacing of fig. 3 as compared with fig. 2 occurs only when the grating is placed so that the slit is parallel to the vertical line of fig. 3, and not when any other line is vertical, except by some odd chance connected with the shape of the pits. In this way it is possible to distinguish between fig. 2 and fig. 3. The mode shown in fig. 4 is distinguished by the halvings of both the horizontal and vertical spacings, and of no others. In the case of fig. 6, as compared with fig. 1, the spacing is halved when the slit is parallel to the horizontal or the vertical line of the figure, and also whenever the grating is so placed that the parallel to the slit passing through one of the corners of a cell does not pass through the centre of that or any other cell, as, for example, if EO but not EK is parallel to the slit. It is therefore easy to distinguish each of the four modes.



z
y
x
D^xD^y or C^1_{2v}
$D^xE^y_z$ or C^2_{2v}
$E^y_zE^x_z$ or C^3_{2v}
$D^xE^y_x$ or C^4_{2v}
$E^x_yE^y_z$ or C^5_{2v}
$M^xE^y_z$ or C^6_{2v}
D^xM^y or C^7_{2v}
$E^x_yE^y_x$ or C^8_{2v}
$M^xE^y_x$ or C^9_{2v}
M^xM^y or C^{10}_{2v}

Fig. 7.

Similar methods are applicable to the three-dimensional crystal. If, for example, we consider the case of C_{2v}^{2} or $D^{x}E_{z}^{y}$ we can show that, whereas in general the spacings of planes are such as are proper to a cell of the dimensions and form drawn in the figure, all planes of the form $lx/a+mz/c=$an integer, show halved spacings, unless l is odd and m is even: which is sufficient identification of the mode of arrangement. The symbols a and c denote edges of the cell.

If we follow this line of reasoning through all the thirty-two classes, we end, of course, with the discovery of the 230 modes which are known to exist: and with the identification marks of each, with certain qualifications. These last are of two kinds. One of them is general in nature and is a consequence of the fact that the X-rays can measure only the distance between two like points in neighbouring cells, say A and B. But they do

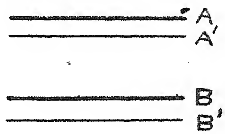


FIG. 8.

not indicate any difference that may exist between AB and BA. If such a difference exists it may be expected to show in the external characteristics of the cell, giving it polarity. A good example is to be found in zinc blende. Layers of zinc and of sulphur atoms alternate with one another as in fig. 9, all of them being perpendicular to a trigonal axis of the crystal. The distance between a zinc atom in the layer A to a zinc atom in the layer B is found without question by the X-ray method. Now we know from observation of the crystal that there is a difference between AB and BA: the crystal is polar. A crystal plate cut so that its faces are perpendicular to the axis shows different properties on its two sides: if heated, one face becomes positively and one negatively electrified. Whichever face we use in the X-ray spectrometer we obtain the same value for the spacing, and we find ourselves unable to detect any difference between the two aspects by means of the spectrometer observations.

We may see this point in another way. Suppose that fig. 9 represents a section of a crystal consisting of two kinds of atoms, indicated respectively by full and empty circles. The arrangement clearly has no symmetry about a vertical line in the plane of the paper. But if X-rays were incident from above, as shown there would be equal reflections from the planes 11′ and 22′. If the incident rays were heterogeneous and a photographic plate were placed to receive the Laue reflections in the usual way, there would be a symmetry distribution of spots on either side of A, although there is no symmetry in the crystal to correspond.

It is only when we have taken other considerations into account and have determined the structure that we can establish the polarity of the crystal. We may take, for example, the fact that zinc blende is cubic, and therefore has four trigonal axes, a fact which we may discover from X-rays as well as from the external form. Also, the unit cell contains only one molecule of zinc sulphide, and may be drawn of the same form as in diamond: that is to say, its eight corners can consist of the six centres

of cube faces and the two ends of a diagonal. If we put zinc atoms at the corners of the unit cell, the sulphur atom must lie either at the centre of the unit cell or at the centre of the regular tetrahedron formed by four of the corners of the cell: only by the adoption of one of these alternatives do we get the four trigonal axes. The former gives the rock-salt structure and is distinguished by the fact that the (100) and (110) spectra decrease regularly in intensity from lower to higher orders, whereas in the (111) spectrum the even orders are relatively greater than the odd. In the latter

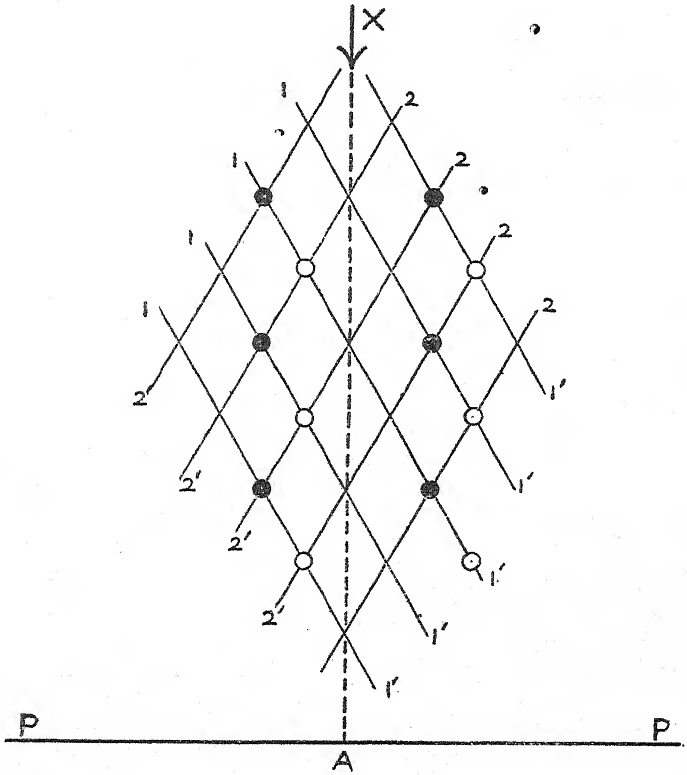


FIG. 9.

alternative the even orders of (100) are relatively greater than the odd, (110) spectra are normal, and the second order of the (111) is abnormally small. It is easy to distinguish between the two cases. The latter is adopted by zinc blende. Each atom has the symmetry of Class 31, to which the crystal belongs, there being only one atom of each in the unit cell.

In this case we are successful from X-ray measurements alone in determining the mode of arrangement of the crystal, although the crystal is polar and the X-rays cannot detect polarity directly. We have been able to determine the structure completely, and the polarity then appears.

When the determination of structure cannot be carried far enough, the X-rays may fail to decide between the presence and absence of polarity. For example, resorcinol is an orthorhombic hemihedral crystal: this is known by its external form. The X-rays show that, this being so, its internal arrangement must be that of M^xM^y or C_{2v}^{10} in fig. 7. If we had no help from the study of external form, or from any other source, we should not be able to decide between C_{2v}^{10} and the more symmetrical mode known as Q_h^{12}: the symmetry of the latter is obtained by adding a centre of symmetry to the elements of symmetry possessed by C_{2v}^{10}: that is to say, by removing the polarity of the crystal. As a matter of fact, the external form of resorcinol clearly shows polarity: or, if we could be sure that the molecule had no symmetry, we could infer that the crystal was unsymmetrical about the *xy* plane, there being only four molecules in the cell and all these being wanted to give the symmetry observed by X-rays. Thus there are cases where the X-rays cannot decide between two modes, one of which can be derived from the other by the addition of a centre of symmetry. As, however, the existence of a centre of symmetry can generally be decided by other means—for example, by such means as I have described above in the case of zinc blende or of resorcinol—this incapacity of the X-ray method is of no great consequence.

The addition of a centre of symmetry moves a structure from one class to another—Class 1 to Class 2, Class 31 to Class 32. Consequently, the X-ray methods are by themselves sometimes in doubt between two modes in different classes when they are rarely in doubt as to the mode within a class. It will readily be understood that the doubt as to class may be of far less importance than the doubt as to mode; though hitherto the former kind of difference has been given all the attention because it has been the only kind that could be observed. A very slight relative movement of the atoms would be sufficient to reduce the symmetry of the crystal from one class to another: but the change from one mode to another within the same class would mean a complete re-arrangement of the molecules.

There are two cases in which the X-rays cannot distinguish between two modes in the same class. These are Q^8 and Q^9 in the enantiomorphous class of the orthorhombic system, and T^3 and T^5 in the tetartohedral class of the cubic system. The ambiguity disappears, however, if there are only two molecules in the unit cell, when the former alternative is alone permissible in each case: it would disappear also in any case in which the structure could be determined completely by any other means.

It has been known for many years, thanks to the work of Fedorow, Schonflies and Barlow, that the 230 modes of arrangement represent all the possible forms of internal crystal structure. In each mode of arrangement there is a relative disposition of planes, axes and centre of symmetry, which is characteristic of the mode, and the mode may be described in terms of these symmetries. This was the language used in the original work on the subject, and the term space group was used, instead of the term mode of arrangement, in reference to the particular group of symmetry planes, axes and centre in space. When the subject is approached from the point of view of the X-ray worker, the language of the mode of arrangement has its special conveniences. A list of the 230 modes, and of the X-ray tests for each mode, has recently been published in the Transactions of the Royal Society by Astbury and Yardley. Lists of the same 230 space

groups have already been published in different terms by writers on crystallography: recently a list by Wyckoff has been published by the Carnegie Institution of Washington, in which each space group is expressed in terms of the co-ordinates of the arrangement of points required to give each space group its special characteristics.

It may be of interest to look at these matters from a somewhat different point of view, which takes in the question of the permanence of the chemist's molecule when built into the solid structure.

In every crystal the unit can be divided into a certain number of parts, each of which has no symmetry of its own, but may be made to coincide with any other part by some combination of reflections, rotations and shifts. The number is always either one, two, three, four, six, eight, twelve, twenty-four, or forty-eight. The division into 230 modes of arrangement refers to the arrangements of these parts. In the case of a crystal of the rock-salt type both the positive and negative portions of the cell can be so divided. Very often the part in question is the chemical molecule. For example, the cell of the monoclinic prismatic class can be divided into four such parts. The X-ray measurements show that the unit cell of benzoic acid which belongs to this class contains four molecules. Also they detect the existence of the four parts, and determine the mode of their arrangement. It is natural to make the assumption that each part is a molecule. This, it may be noted, involves the existence of right- and left-handed molecules, as built into the crystal.

Sometimes the division into parts involves the division of the molecule. The molecule then consists of two or three or more parts, and therefore possesses a corresponding symmetry. For example, the naphthalene molecule in the naphthalene crystal contains two parts, and has a centre of symmetry. The molecule of FeS_2 in the crystal of iron pyrites consists of six parts, and has a centre of symmetry and a trigonal axis. Each of the two atoms in the rock-salt cell, sodium and chlorine, has—that is to say its relations to its neighbours have—forty-eight parts, and therefore the full symmetry of the crystal.

Much more rarely a part consists of more than one chemical molecule. So far a few instances have been met with. The 'part' in the crystal cell of sulphur certainly contains two, perhaps more, atoms. Miss Yardley finds that the 'part' in the fumaric acid crystal contains three, perhaps six, of the molecules as ordinarily defined $(COOH.CH:)_2$. In the cell of α-naphthyalmin at least three molecules go to a part. The part has no symmetry, so that the molecules that compose it differ from each other in some way. These are really examples of polymerisation in the crystal.

Is the grouping of the atoms in the molecule as displayed in chemical reactions maintained without change? When the first results of the new methods were published, with their determinations of diamond and rock-salt structure, there was some unnecessary alarm as to the apparent disappearance of the molecule. If there had been anything to suggest a complete disruption of all the alliances in the molecule, which had been so long and so successfully studied by the chemists, the alarm would have been justified. Atomic bonds would have been annoyingly variable and dependent on conditions, and we should have been put back to the starting-point in the investigation of the solid. This condition of things appears, fortunately, to have no existence. The conclusions of chemistry are carried

into the solid, with only such modifications as might reasonably be expected. Our new science is in full and close alliance with chemical science already established: it is in fact a constant and delightful experience to find some direct confirmation or illustration of an inference already drawn from other sources. So far as experience has to tell us, the chemical molecule generally takes its place as such in the crystal structure with little change.

To sum up, we are now able to replace the rough division into thirty-two by the finer division into 230. This is advancing a whole stage towards the final solution of the structure problem. We carry the analysis right up to the limits which can be foreseen by the mathematical investigation of the geometry of Space. We require only a sufficient number of X-ray measurements: if these can be obtained, the crystal then—with certain additional information as to polarity—can be assigned to its particular mode or space group, with one or two exceptions as already noted. It may be that the structure of the crystal is so simple that having got so far the full solution is already in sight. In the vast majority of cases this is not so; we have only come to the end of the second stage of the work.

The first stage was complete when we had found the dimensions of the crystal unit cell: the second is completed when we know which of the 230 possible arrangements of molecules, or, in other words, space groups, the crystal structure follows.

If the structure of the crystal is not yet obvious—and in the great majority of cases this is far from being the case—we enter on a third stage, in which the mode of procedure is less stereotyped and more difficult, perhaps all the more interesting. We have now to find, if we can, the arrangement of the atoms within the cell, to which task the knowledge already gained is an indispensable though, it may be, a quite insufficient contribution.

As I have said already, the X-rays do not tell us directly the relative positions of the atoms within the unit cell. They have, however, much to tell us as to the relative intensities of the different orders of reflection by each plane, and these must depend on the atomic arrangements. It is to be admitted, however, that we are as yet unskilled in the interpretation of this evidence. We do not completely understand how varying conditions affect intensities of reflection, though we have learnt a great deal through the work of W. L. Bragg, Darwin, Compton, and others. And, of course, when the cell contains many molecules, their positions being as yet unknown and their separate contributions to the intensities in any case doubtful, the observations of intensity are very difficult to make use of, though they can be accurately measured. We can only avail ourselves of such bold indications as that a very strong reflection implies the location of many atom centres on or near the plane in question, particularly if there are higher orders: or we may find ourselves able to show that an especially strong second or third or other order implies the adoption of some particular alternative arrangement. A very interesting example of a general influence of form upon intensity is to be found in the reflections from the fatty acid layers which have been investigated by Muller and Shearer. The first, third and other odd orders are much more intense than the second, fourth and other even orders. A simple explanation is found in the fact that these long chains face opposite ways alternately, and that the number of scattering centres is distributed fairly evenly along their length. At the ends, however, the uniformity of distribution is interrupted; at one end,

probably the carboxyl end, there is an excess per unit length; at the other, the methyl end, a deficiency. Thus we may say that the effect on an odd order of the spectrum due to a single layer, the thickness of a layer being twice the length of a molecule, contains a factor :—

$$\mathrm{A}\ \sin(\omega t-\alpha)-\mathrm{B}\ \sin(\omega t-\alpha-\overline{2n+1}\pi)=(\mathrm{A}+\mathrm{B})\ \sin(\omega t-\alpha).$$

The factor for an even order is :—

$$(\mathrm{A}-\mathrm{B})\ \sin(\omega t-\alpha).$$

If at both ends there had been an excess of scattering centres, we should have found the even orders stronger than the odd: the effect we find, for example, in the (111) planes of rock-salt. In the case of the simpler inorganic crystals like rock-salt, diamond, and so on, intensity observations are conclusive as to the structure: in the case of iron pyrites or calcite they are very nearly so. But in the case of quartz, where the cell contains nine atoms, still more in the case of an organic compound, they do not carry us very far. We hope that greater experience will give us in the future the power of using them to better advantage.

In what other direction then shall we look for additional means of approaching more nearly to the final solution of the problem of structure?

The answer to this question will take account of all the store of physical and chemical knowledge which we already possess. Having solved, wholly or in great part, the structure of some of the simpler crystals, and being able to proceed in all cases, even of the most complicated crystals, to the determination of the number of molecules in the cell, and of their mode of arrangement, we must try to correlate what we have found with the properties of the crystal. By that means we shall become gradually more certain of the general connection between the structure and its physical and chemical properties; we shall become able to settle further structural details in various cases, and so, by alternate and mutually supporting advances, we may hope to reach our goal.

Let us consider what is being done in this direction. First of all there is the question of the distribution of the atoms in space. Given so many atoms, to be packed into a cell of known dimensions, what information have we as to the space that each must occupy? The answer to the question cannot be simple, because we may not expect that the atoms are always to be treated as spheres, still less as spheres of constant radius. It is as generally difficult to state the distance between one atom and another as to state the distance between a table and a chair. Nevertheless, the atom-radius is a useful conception, especially when its dependence on the nature of combination is taken into account. The question has been considered by W. L. Bragg, Wyckoff, Davey, and others, and it appears that an atom does make a definite contribution to the distance between its centre—when it can be assumed to have a centre—and the centre of a neighbour, so long as the nature of the bond remains the same. This is a valuable contribution to the study of structure. It is proved by the examination of simple structures like those of the alkaline halides, and we may assume its reliability in our attempt on more complicated problems. And, of course, it is interesting from the point of view of atomic structure itself, and atomic linkages.

The radius seems to depend on the tightness of the bond as in bismuth

or in graphite, where there are two kinds of bonding, and the plane of cleavage cuts across all the longer distances from centre to centre. In calcium fluoride the centres of calcium atoms are closer together than they are in the metal itself in spite of the interposition of the fluorine atoms; and in calcium oxide they are still closer. The change in the type of the bonding has altered the value of the radius.

There is also the very interesting but still more unsettled question of the mutual orientation of the bonds between an atom and its neighbours. It is, of course, the carbon atom which is the occasion of this problem in its most pressing form. In the diamond the exactly tetrahedral arrangement of bonds is associated with great rigidity, which implies great stiffness of orientation. The analysis of the structure of graphite has lately been carried by Bernal to a stage very near completion, but the only point in any doubt is unfortunately the very one as to which certainty would be welcome. Has the great weakening of one bond interfered with the relative orientation of the other three? Debye thought that the structure was trigonal, and that the atoms were arranged in layers which were like the layers of diamond, except that they were flattened out without a sideways extension of the network. This would involve a closer approach of carbon atom centres from 1·54 A.U. to 1·45 A.U.; against which no obvious objection can be offered, but it would be interesting to know how it happened. Hull believed the structure to be hexagonal, and that the layers remained as in the diamond. Bernal, having found some good graphite crystals to which the single crystal methods could be applied, finds that Hull is correct as to the hexagonal structure, but inclines to the belief that the layer is flattened. In the latter case, we must suppose that the carbon atom has three very strong bonds almost coplanar with the carbon, and one weak bond at right angles to this plane.

The question arises in another form in the investigations of the long carbon chains by Piper and others, and especially by Muller and Shearer. If the chains are formed by the linking of carbon atoms together in such a way that the junctions of one atom to its two carbon neighbours are inclined to one another at the tetrahedral angle of 109°28′, as in diamond, then there are three possible forms of chain. In one of them, each two carbon atoms imply an increase of 2.00 A.U. in the length of the chain, and, in a second, an increase of 2.44 A.U. In these two cases the carbon atoms of a chain can lie in a plane. With one exception, all the cases examined show one or other of these two rates of increase. The third form of chain is a spiral, for which the growth of each single atom added is 1.12. In one case this rate of increase is found to hold: it is that in which the chain contains a benzene ring. This agreement between calculation and experiment shows with some force that the relative orientation of the bonds is maintained. Even when two or four hydrogens are stripped from the chain at various points, so as to leave a double or triple bond between consecutive carbon atoms, to adopt the ordinary chemical language and theory, no measurable change is found in the length of the chain. This does not mean that there is no change in the distance between neighbours: such a change would be small and might escape detection. But it does mean that there is no great change in the general straightness of the chain, such as might be expected from any large change in the mutual orientation of the bonds between the carbon atom and its neighbours.

In calcite the three oxygens which surround a carbon atom must lie in one plane. It is supposed, however, that in this case the bonds are electrostatic: the carbon atom has lost its four valency electrons, and with them its powers of tetrahedral orientation.

Now if we can discover the extent to which an orientation is maintained under different conditions we are provided with one more guiding principle in our attempt to discover the structure of the crystal which contains carbon atoms. And, of course, the organic compounds centre round the carbon atom and its tetrahedral structure.

The question of orientation in respect to other atoms is more obscure, but it is clearly one of importance. There must be some reason why ice has such an open structure, and here the oxygen atom is largely concerned. In the ruby the oxygen atom has no plane of symmetry in relation to its neighbours. In organic substances the great emptiness of the structure implies that atoms are attached to one another at points which have definite positions on the surfaces of the atoms and are limited in number. And, generally speaking, the consideration of organic crystal structure is against any idea that atoms and molecules are to be treated as spheres surrounded by uniform fields of electric force, except in certain cases where by loss or gain of electrons an atom has been reduced to the outer form of one of the rare gases. They must have highly irregular fields, having forms which more or less resist any change. The weak bonds which hold molecule to molecule in the organic substance are not due to electron sharing as in diamond, or to ionisation as in rock-salt, but to an intermingling of stray fields belonging to definite positions on the surfaces of the molecules.

Our attempt to discover the effect of orientation is part of a general attempt to discover the field of force of the atom, which is naturally a very difficult matter. But if we can learn only a few rules, even empirical rules, we are so much the further on our way.

Yet another obvious and most important source from which help may be obtained is to be found in chemistry itself. Although the chemist has had no means until now of measuring distances and angles, he has been able to build up a wonderful edifice of position chemistry. An atom A of a molecule is certainly linked, it may be to B, and not to C; or again, of a number of atoms of the same nature and contained in the same molecule, so many must be alike, and so many may be different.

The chemist has, for example, come to the conclusion that the naphthalene molecule is a double benzene ring, and the anthracene a triple benzene ring. The X-ray observations show that one of the sides of the unit cell of the latter crystal is longer by 2·5 A.U. than the corresponding side of the other, all other dimensions of the two cells being very nearly the same. The width of the hexagonal ring in the diamond is 2·5 A.U., so that on the one hand the chemical evidence suggests that the length of the molecule is parallel to that edge of the two cells which shows differing values, and on the other the X-ray conclusions give material support to the chemical view. Let us take another example from basic beryllium acetate $Be_4O(C_2H_3O_2)_6$. The substance is remarkable for the ease with which it sublimes into a vapour consisting of whole molecules, from which we may infer that the molecule does not suffer much change in the process. The relative positions and mutual alliances of the atoms are nearly the same when the molecule is free as when it is built into the solid. From the

X-ray evidence we learn that the molecule has four intersecting trigonal axes. We must place the unique oxygen at the centre of a regular tetrahedron, and the four beryllium atoms at its corners. Each of the six acetate groups must be associated with one of the tetrahedron edges, and in such a way that the four trigonal axes are maintained. This necessitates, as crystallographic theory shows, the existence of a dyad axis through the middle points of each pair of opposite edges of the tetrahedron. The $C_2H_3O_2$ groups must be added so as not to interfere with the existence of these axes. If they are placed correctly for the trigonal axes, each of them has a dyad axis of the kind mentioned. All this agrees with the chemical evidence as partly stated in the formula, which implies :—

1. That there is one oxygen differently situated to the rest.
2. That the four beryllium atoms are all alike.
3. That the acetate groups are all alike.

Further, chemists would say that the carbon atoms are not alike ; in that case, they must both lie on the dyad axis, since if they did not they would necessarily be symmetrically placed with respect to that axis and would be equivalent. On the other hand, the oxygen atoms in the acetate group cannot lie on the axis if, as is probable, they are equivalent to one another. They must be placed symmetrically with respect to the dyad axis. As to the hydrogens, we must assume either that they do not count, which is not at all unlikely, or that they are not all alike. It is impossible to place eighteen hydrogen atoms so that the group has four intersecting trigonal axes and that every hydrogen is like every other. The molecule has no plane of symmetry, the fault lying with the oxygens. It could not be due to the hydrogens because there are marked differences in the intensities of reflection of pairs of planes, which differences would not exist if there were planes of symmetry, and would be small if due to dissymmetry in the positions of hydrogens only. It is by reasoning along such lines as these that X-ray evidence and chemical evidence can help each other. Many other instances might be given ; indeed, no complex crystal can be studied with success without calling in the assistance of chemical arguments.

A fourth example of the connection between arrangement and properties is to be found in the recent work by W. L. Bragg on the indices of refraction of crystals. It has been found possible to calculate the indices of refraction of calcite, given the dielectric capacities of calcium, carbon and oxygen atoms separately. The difference between the two principal refraction indices is almost entirely due to a difference between the dielectric capacities of a set of three oxygen atoms, at equal distances from one another, when placed :—

1. So that the plane in which they lie contains the direction of the field.
2. So that this plane is perpendicular to the field.

If we are able to calculate the refractive indices on these data, then it must be possible to find conditions governing the arrangement of the atoms, when we know the composition of the crystal and its refractive indices. For instance, the near equality of the refractive indices of potassium sulphate implies that the dielectric capacity of the SO_4 group is much the same in all directions, and this is in agreement with the hypothesis that the

oxygen atoms are grouped in some sort of tetrahedral fashion about the sulphur atom.

There are still other connections between structure and properties which we begin to understand, and can use in proportion to our understanding. The cleavage plane, and the occurrence of certain faces in preference to others are connected with the nature of the bonds and the size of the spacings. We are not surprised to find that in bismuth, or graphite or naphthalene, the cleavage plane cuts across the ties which we should expect to be the weakest of those that bind the molecules together; or again, that natural faces follow the planes that are richest in atoms or molecules and may be assumed to contain relatively large numbers of linkages. In naphthalene the cleavage plane passes between the ends of the molecules, where the β hydrogens are, and where there is a deficiency in the number of scattering centres, as the X-rays indicate by the strengths of several orders of the (001) reflection. The other faces found on the crystal cut across the ties at the positions of the α hydrogens.

There are many other connections between the structure and other properties of a substance, such as dielectric capacity, rigidity, and compressibility, conductivity both thermal and electric, magnetic constants. In fact, the only properties of solid bodies which are not directly and obviously related to crystal structure are those, few in number, that depend on atomic characteristics alone, such as weight; and the absorption coefficients for α, β, γ and X rays, all the rays which involve high quantum energies. With few exceptions every aspect of the behaviour of a solid substance depends on the mode of arrangement of its atoms and molecules. We have, therefore, an immense field of research before us, into which the X-ray methods have provided an unexpected and welcome entrance.

They tell us directly, as I have said, the number of molecules in the crystal unit cell, and the mode of their arrangement with such determination of lengths and angles as are required to define the mode of arrangement in full. They leave us then to ally our new knowledge to all that we possess already as to the physical and chemical properties of substances. By this comparison we hope in the end to determine the position of every atom, and explain its influence through its nature and position upon the properties of the substance. It is the chemistry of the solid that comes into view, richer in its variety even than the chemistry we have studied for the past century, and possessing an importance which is obvious to us all. Every side of scientific activity takes part in this advance, for all sciences are concerned with the behaviour of matter.

SECTION B.—CHEMISTRY.

CHEMISTRY AND THE STATE.

ADDRESS BY

Sir ROBERT ROBERTSON, K.B.E., F.R.S.

PRESIDENT OF THE SECTION.

CONTENTS.

INTRODUCTION.

It should be premised that in this account of the relationship of the State to chemistry in Great Britain, an attempt has been made to limit it to a description of the more or less direct assistance given by that science to various departments as they came into being or took form. Only in recent years, and as a result of the war, has there been a direct recognition of a corresponding obligation on the other side.

It is obvious that it is to the universities, and, as was the case to a greater extent in the past, to private workers, that the great advances made by British chemists are due. Departmental requirements have, of course, reaped the advantage of these advances, but examples of important contributions to chemical knowledge emanating from the departments themselves are not lacking. The collected story of their connection with the activities of the State may be worth reciting, if it should show the development of its appeal to chemistry, and illustrate the gradual breakdown of the view held by the chief of the tribunal before which Lavoisier came, that ‘ the State has no need for chemists.’

We will find that their employment in an official capacity was in the first instance in connection with the State’s pressing necessities, such as its defence, the regulation of its currency, and the collection of its revenue, all of them subjects warranting the maintenance of equipment and staff.

As the need for safeguarding the nation’s health, well-being, and the quality of its food-supply became recognised, legislation followed, frequently

based on the work of Commissions on which sat distinguished chemists of the day, and it became necessary to set up a State chemical department to assist in carrying this into effect.

For some time the science of chemistry had received a limited and vicarious assistance from State grants to the late Science and Art Department and to the universities, but it was reserved for the war to establish definitely and finally the position that the whole future existence of a State might and probably would depend on the existence of a flourishing and efficient chemical industry. This resulted in the definite steps of assisting the application of science to industry, and providing direct encouragement for workers in the purely academic field.

It is proposed, therefore, to sketch the development of the main chemical activities of the State, and to review the conditions in Great Britain in the hope that it may be of use generally to define the present position, and perhaps of interest to this Dominion in the present stage of its chemical development.

Defence.—Explosives.

It would appear that the importation of the technical process from abroad is no new thing, for it is stated that in 1314 gunpowder and guns were being imported into England from Ghent. Not only the material but the executant also appears to have been imported in the person of a John Crab, a Fleming, who took service with the English and supervised the guns and munitions used at Crécy. By 1338, cannon were mounted on board English ships of war, and in 1346 gunpowder was being supplied to the King. Although the manufacture of gunpowder is mainly a mechanical operation, variations in the composition which must have involved chemical experiment are recorded in such works as the 'Fire Work Books' of that interesting class, the Master Gunners. In England, a Master of the Ordnance in 1447 is stated to have made 20 tons of gunpowder. This manufacture, however, early became stabilised, and the proportions of the composition underwent little change until the middle of the nineteenth century, when it was modified, but as freedom from smoke began to be demanded a new propellant of a type that could be produced only by chemists was evolved.

It is of interest that Faraday was employed by the War Office as Lecturer at the Royal Military Academy from 1829 to 1853, and on appointment took as his assistant James Marsh, whose name, associated with the process for determining arsenic, is so well known to chemists. Marsh received the gold medal of the Society of Arts for this work, and a silver medal from the Board of Ordnance for his discovery of the quill percussion tube for cannon, and further he devised some of the earlier types of time-fuze. Abel succeeded Faraday at the Academy and began his long career of activity as scientific adviser to the War Office, becoming War Department Chemist in 1854.

It is necessary to mention some of the important advances made by Abel and his staff, including Kellner and Deering. By pulping guncotton, he rendered it safe to handle and store; his researches on the properties of guncotton laid the foundation of later work on its stability and explosive properties; and his research (with Noble) on the behaviour of gunpowder when fired is an example of a thorough investigation. Abel was consulted

also on subjects other than explosives, and in his laboratory were conducted experiments which led to the adoption in 1879 of the present close-test apparatus for testing the inflammability of oils, experiments on steels and the effect of foreign materials in them, experiments on dangerous dusts and on the cause of accidents in coal mines.

The work of Abel in rescuing nitrocellulose from the position of an erratic substance, liable to decompose and explode on storage, led to its use as a reliable explosive, not only for military purposes, but also in commercial compositions, such as sporting powders and blasting explosives.

When it became necessary to devise a smokeless propellant for the British Service, the chemical work was in the hands of Abel with his assistant Kellner, Dewar, and Dupré, and in 1890 this resulted in the recommendation for the adoption of cordite.

It now became necessary to extend the only chemical manufacture carried on at the Royal Gunpowder Factory, that of guncotton, by adding the manufacture of nitroglycerine, the technical handling of cordite, and plant for treating acids, and accordingly in 1891 a chemical manager of this section with a staff of chemists was appointed.

The chemical work carried out by the British Government for defence, both as to its immediate object and as to its reaction on the explosives industry of the country, is worth review. In such a review the position before the war may first be described. Propellant manufacture was seriously undertaken, the small quantity of high explosive used at this time being mostly obtained from private manufacturers. Guncotton, as has been stated, had been manufactured by Abel in a fairly stable form, and this explosive was chosen for the Service propellant cordite, together with nitroglycerine and mineral jelly, the mixture being gelatinised by acetone, so that in a plastic condition it might be squirted into the cords which give it its name. A close study was devoted to this manufacture in all its aspects; the processes of manufacture were greatly improved, and the dangers reduced.

The Royal Gunpowder Factory took its place as a model of an explosives factory, and afforded an example of what could be done by a State department in conducting a scientific manufacture with regard to improved technique, economy, and efficiency. Thus the method of nitration to produce guncotton was greatly improved in safety, freedom from fumes, and ultimate stability of the product, by the adoption of the process of downward displacement of the waste acids from the nitrated product by a layer of water; for nitroglycerine a displacement process by which the layer of that liquid, separating on the surface of the waste acids, was caused to overflow from the top of the vessel by introducing waste acid from a previous charge at the bottom, led to an increased safety and yield, and saved height in the erection of a factory; the chemistry of the process of guncotton boiling was worked out and placed on a scientific foundation; and acetone, which in the process of drying the cordite had been allowed to escape into the air, was recovered from the drying stoves and saved for further use. These advances in manufacturing method were taken up by other manufacturers, both in the United Kingdom and abroad.

In the technique of the manufacture of propellant explosives before the war this country then had advanced to a high pitch of efficiency, so

that when the demand came for enormously increased quantities of propellants, new factories, such as that of Gretna, took up the manufacture on lines already well established.

Safety in manufacture had also been closely studied, and precautions introduced that commended themselves to private firms. It may be said in this connection that the application of the Explosives Act of 1875 by the Home Office Inspectors of Explosives has been of much benefit to the explosives trade in reducing casualties. Perhaps in no other country are precautions taken to such an extent as in Great Britain, so that to visitors from abroad they sometimes appear unnecessary and vexatious, but experience has shown that the policy is sound, especially as it brings into all sections of the work an atmosphere of carefulness and responsibility, with an eventual gain in health of the workmen and freedom from accidents.

Research on explosives before the war was carried out at the Royal Gunpowder Factory and at the Research Department, Woolwich. At the former establishment, the chemistry of the products manufactured was investigated, especially with regard to the mode of decomposition of guncotton, of nitroglycerine, and of cordite; their respective rates of decomposition at different temperatures were determined, a subject bearing on their behaviour on storage. Knowledge of this kind is essential in a Service such as ours, on account of the extremes of temperature from tropical to frigid to which explosives may be subjected in stations throughout the Empire.

At Woolwich an experimental establishment had been set up on the instigation of Lord Haldane to deal with explosives and metals used in gunnery. Here the study of the chemical and explosive properties of all types of explosives was undertaken and methods were developed for determining their stability and sensitiveness. This knowledge found application in laying down criteria for the choice of explosives for use in a Service whose demands are exigent on account of the drastic conditions above mentioned, affecting both storage and the design of mechanism containing explosives. So far as the subject-matter is not considered to be confidential, this work has been published in scientific journals, so that it is available in connection with the study of the theory of explosive substances.

A new phase was entered with the declaration of war, and ultimately all chemical help was mobilised for the defence of the realm. A nucleus existed at Woolwich, where the small staff of eleven chemists had been occupied in the study of explosives and their application. In two directions this experience proved of importance, for it enabled immediate answers to be given to questions which would otherwise have necessitated protracted storage trials, and it afforded the staff the training necessary to qualify them to meet the fresh demands that became urgent on the outbreak of hostilities.

After the beginning of the war the increase of work imperatively called for a larger staff, and more chemists were appointed, until at the beginning of 1917, the home supply being exhausted, permission was obtained to withdraw from France members of the Special Brigade, R.E., of whom more than thirty were transferred to the Department. Finally, the chemical staff numbered 107 chemists and physicists distributed in an organisation which had been gradually evolved, comprising sections for

dealing with different classes of work, such as organic chemistry, physical chemistry, analytical and general chemistry, physical investigation, calorimetry, stability, pyrotechny, applications of high explosives, fuze design, and records.

The manufacture of high explosives had not previously been undertaken by Government, and the known processes for making trinitrotoluene, which was early chosen as a Service high explosive, were unsatisfactory. One of the first subjects, therefore, taken up after the outbreak of war was the provision of an efficient and rapid process for the manufacture of trinitrotoluene, especially without the use of fuming sulphuric acid (oleum). From the results of a large series of nitrations in the laboratory, a process was evolved characterised by several novel features, and this was put to the proof on the semi-industrial scale of a quarter ton, a plant being designed and erected in the Research Department, Woolwich, for nitration, including appropriate arrangements for the mixing and concentration of acids. This small plant substantiated in a remarkable way the process evolved from the laboratory work, and from the start turned out trinitrotoluene of good quality and yield. The process found immediate application in the large Government factories that were designed and erected by Mr. Quinan and also in numerous private works built at this time. The small-scale plant mentioned was used also for the purpose of training chemists, who proceeded to operate chemical plant in Government and private factories.

A study of trinitrotoluene in all its aspects was undertaken, and much attention devoted to its chemistry, the proportions in which the isomers occur in the crude product being determined by thermal analysis, and investigations were made on their interactions, stability, sensitiveness, heat values, and explosive properties. Most of the scientific results of this work have since been published.

When it became evident, as it soon did to Lord Moulton, that the supply of high explosives in use, lyddite and trinitrotoluene, would not suffice, the Research Department put forward mixtures of ammonium nitrate and trinitrotoluene, the amatols, as a result of a study of their properties and of their effects in shell-bursting trials. Gun trials confirmed these trials at rest, and the adoption of amatol as a high explosive quickly followed. Various methods of filling these mixtures into shell were at this time worked out, and many of them were applied on the very largest scale.

It was found that 80/20 amatol (80 parts of ammonium nitrate to 20 of trinitrotoluene) was less easy to bring to detonation than lyddite or trinitrotoluene itself, and it required special arrangements in the train of initiation of detonation. These were successfully devised, and good and trustworthy detonation of our shell was secured. Ultimately, amatol became practically the only explosive for land and aerial warfare, and justified the early estimate of its properties and capabilities. It is economical in that it makes use of a cheap ingredient, and has explosive properties that render it very suitable for the purposes for which it is used. In 1917 the production was at the rate of about 4,000 tons a week.

The Department continued the study of amatol, especially with regard to its chemical stability and compatibility with the various materials with which it came into contact. Certain impurities in ammonium nitrate were discovered to be objectionable, and investigation of these led to an

improvement in the purity of the ammonium nitrate supplied. The manufacture of amatol and the modes of filling it into shell occupied the attention of a large staff of chemists attached to the factories, and an increase in knowledge of its chemical and physical properties led to improved methods of handling it.

The Service propellant cordite required for gelatinisation in the course of its manufacture the solvent acetone, of which the supply ran short when the programme for propellants began to exceed all previous calculations. To meet this situation, cordite of the existing type was retained for Naval Service, but for Land Service a modification was introduced under the name of cordite R.D.B. (Research Department powder 'B'). This propellant could be made without any alteration in the plant required for the manufacture of cordite. Instead of acetone the solvent employed was ether-alcohol, and instead of guncotton a lower nitrate of cellulose was used. The great factory at Gretna, also built by Mr. Quinan, manufactured cordite R.D.B. exclusively, and this soon became the only propellant made in this country for the Land Service. It was produced both by Government and by private firms in enormous quantities. The alcohol was made in the country from grain, and ether was produced from it, so that dependence on sea-borne solvent was reduced. It was this need for alcohol that led to the restrictions imposed on that liquid when used as a beverage.

Numerous problems arose in connection with these manufactures as they developed and in the application of the explosives in the various types of ammunition, and these necessitated the study of the explosives in all their aspects. A large addition to the knowledge already existing was thus acquired on the more theoretical side of the study of explosives, and much of this has been made available by publication.

As the demand on our resources increased, and the necessity grew for investigating every source of supply and possible alternative, it came to pass that nearly every professor of chemistry in the country was mobilised for investigation in this field and in that of chemical warfare, and much valuable work was done by them, both of a research and inspectional nature.

For the manufacture of explosives and the operation of filling them into munitions of various kinds in the existing factories and the new ones which sprang up, a large staff of chemists, amounting to about 1,000, was required, and in this way many chemists whose earlier work lay in quite other directions, such as at the universities or in teaching posts, received an insight into technology and took control of workmen.

During the war itself, instructional work in this subject was not wanting, for current progress in the factories under his control was discussed in a systematic manner by Mr. Quinan with representatives of his staff, a course which led to important improvements. Although most of these war-time plants for the manufacture of explosives have been dismantled, much of the technical experience gained has been saved, and will be found incorporated in a series of memoirs (Technical Records of Explosives Supply) published by H.M. Stationery Office. The information set forth in these volumes is in a form which has a much wider appeal than to the explosives technologist only, and their study is commended to those who take up the subject of chemical technology in any of its aspects.

In addition, factories for the production of substances not in themselves explosive equally required the services of chemists, and many were employed in the production of such substances as methyl alcohol, acetone, and acetic acid.

Instruction in chemistry is provided by the Fighting Services for Naval and Marine cadets at Dartmouth, and for Army cadets at the Royal Military Academy and the Royal Military College, Camberley. For selected officers, both of these Services have a professorial staff for providing systematic courses in theoretical and practical chemistry, with special reference to Service applications, at the Royal Naval College, Greenwich, and at the Artillery (formerly the Ordnance) College, Woolwich.

Defence—Chemical Warfare.

While our well-developed position of the great inorganic chemical manufactures was a source of strength when the demand came during the war for an enormous production of ammonium nitrate, for example, our neglect to foster a great organic chemical industry led to dangerous delays and improvisations. This was apparent from the beginning when several universities had to co-operate to produce a sufficient supply of local anæsthetics, and when presently our lack of dyes, photographic developers and sensitisers revealed our former dependence on foreign supplies. In November 1914 the Royal Society had set up a Committee to assist the Government, and this became an Advisory Committee when, after May of the following year, the gas attack caused the British Government, which up till then had scrupulously refrained from its use, to retaliate with that weapon. Special companies were created of chemists whose work often had little of a chemical aspect, but many of these men, in twelve to eighteen months, had to be withdrawn for research and control of plant. Chemical advisers were appointed to the armies and for liaison purposes, a central laboratory for rapid identification was established in France, and co-operation was effected with the physiologists. At home assistance was afforded to chemical contractors, and the manufacture of respirators to meet needs rapidly becoming more complex was carried out with great vigour and efficiency. The increasing importance of gas warfare led to a proving ground at Porton being acquired, when the research which had been carried out at the Imperial College at South Kensington became centralised there. As the final proof of explosive projectiles is carried out at Shoeburyness, it was now possible on this new proving ground to settle questions relating to the filling and correct performance of chemical shell, thus enabling the Chemical Warfare Designs Committee to recommend ammunition to meet the needs of a situation which was continually developing, until the proportion of chemical shell compared with high explosive shell was finally a large one.

In the ramifications of this work all the chemical skill in the universities not already applied to explosives was mobilised, since the demand for new designs involved the manufacture of new substances for shell, bombs, and grenades, new smoke and incendiary compositions, and continuous research and experimental work both on the offensive and defensive sides.

In a few cases only was the country capable of expanding its existing manufactures, as in the case of phosphorus and chlorine; it was not equipped for the home production of phosgene, arsenical compounds, or mustard gas. New factories had, therefore, to be erected and staffs specially trained, in striking contrast to the existence in Germany of standardised plant capable of rapid transference from one purpose to another with little alteration: an example of this was their manufacture of arsenical preparations in the azo-dye sheds.

As a result of an intensive study of absorbent substances, our respirator was never beaten, and it is claimed that, although our output was smaller, the better employment of gas, tactically for surprise, lay with us. Starting late and entering a field entirely new, we were able while there was yet time to protect the soldier, and to make a reply on the offensive side that was rapidly becoming more and more effective.

Not all of the work specially devoted to chemical warfare has been without its effect on peace-time requirements. Thus liquid chlorine, of which very little was made in this country before the war, is now being prepared electrolytically and transported by rail in tank waggons for use in various industries. For the preparation of phosgene, which had been used in Germany in the manufacture of dyes of the triphenylmethane series, better methods were discovered in this country, so that cheaper and purer phosgene is being used here for the first time to prepare the important group of colours known as the Victoria blues. Improved methods are now available for the manufacture of arsenical compounds, such as arsenic trichloride, a substance used for combating the growth of prickly pear in Australia; and mention may be made of the work of Professor Moureu in France on the stabilisation and concentration of acrolein, as it has led to the production of a substitute for celluloid from that body. In addition, the study of many of the bodies used for chemical warfare has been of value from the aspect of the elucidation of their chemical constitution.

Metallurgy.

When the part played by metals in the history of civilisaion is considered, the development of some more durable alloy or some stronger metal appears intimately linked with a distinct advance constituting a new age, often characterised by eponymous association with the metal. As the possession of some superior metal may give ascendency to a people, it is natural that States should show interest in metallurgy, both militarily and to maintain the standard of the medium of exchange. It is thus seen that iron and the precious metals, gold and silver, have for the most part interested the modern State, the metallurgy of the other metals only more recently coming in for attention on military grounds. Accordingly, we find the armourer and the minter holding important positions in early times.

It must be stated at the outset that the relations in Great Britain between the State and metallurgical science before the war of 1914 to 1918 were for the most part sporadic, the great developments in that science being to a large extent independent of the State. It undoubtedly exerted, however, an influence on the nature and quality of metallurgical products, of which it was a large user for warlike, structural, and shipbuilding

purposes, by specifying the conditions of their acceptance: standards established by the Government, often based on enquiry and experiment, gave confidence to other users and resulted in the improvement of industrial materials.

Although iron-making had flourished intermittently since the Roman occupation, and had reached considerable proportions under Elizabeth, no great contribution to knowledge can be attributed to Great Britain in the progress of metallurgy until the restriction of the cutting down of timber for charcoal towards the end of the sixteenth century forced into consideration the use of coal for smelting, the pioneer work being that of Dud Dudley, who in 1642 cast iron cannon at his foundries for the Royalist troops. It was his experience as an Admiralty official that brought Cort, more than 100 years later, to recognise the inferiority of English wrought iron, and to leave the Service for the purpose of improving existing processes so that his successful wrought iron was accepted towards the end of the eighteenth century for anchors and iron work in the Royal Navy. His invention of the puddling process led to great prosperity in the iron trade.

The need to meet Government requirements became similarly urgent in the case of steel, which in its earlier production as puddled steel so failed in uniformity of composition that as a material of construction it could not be used by the Admiralty, nor permitted by the Board of Trade. Bessemer's great advance of converting molten iron cast into steel by blowing air through it, described in 1856 to this Association, enabled him to propose a material more suitable for guns and projectiles than the cast iron then employed. Bessemer steel came into use for many purposes, and its production increased rapidly, but boiler plates submitted to the Admiralty still showed great variations in carbon content. Meanwhile the rival open-hearth process was steadily developed and established by Siemens. In 1875 the Director of Naval Construction had pointed to the danger due to lack of uniformity of steel made by the converter process, but in 1879 he was able to report the success of the new open-hearth steel. The Government challenge had been taken up by Siemens, who produced a steel to meet all its specifications, so causing its acceptance for Admiralty work, and its admission by the Board of Trade for structural use.

After Thomas and Gilchrist had in 1877 solved the problem of dephosphorising iron by the basic process, the Admiralty instituted an enquiry as to its properties, which led to an official recognition of basic steel, thus greatly enlarging the source of supply through the use of native ores.

Among the men who assisted the Government in these enquiries was Dr. Percy, who placed metallurgy in this country on a scientific basis, while lecturing on that subject at the Royal School of Mines and at the Ordnance College. Abel, appointed War Department Chemist in 1854, gave much attention to the use of iron and steel for military purposes, investigating the question of erosion of guns and throwing new light on the constitution of steel by his isolation of Fe_3C. He did good service in convincing the great ironmasters of the importance of chemistry in their industry. To Roberts-Austen also, Chemist and Assayer to the Mint, many Government inquiries and commissions were indebted for advice on the subjects he had enriched by his researches, such as the physical constants and mechanical properties of metals, the effect of impurities,

the cementation of iron, heat treatment, and many others, including the first 'freezing-point' curve of a series of binary alloys in 1875. It was in consequence of these that his co-operation was invited by the Alloys Research Committee, whose first six reports contained a great deal of his work, covered a wide field, and did much towards the realisation by engineers of the value of microscopical and thermal methods in the study of metals. Later reports to this committee, whose work in 1902 was transferred to the National Physical Laboratory, have maintained their high standard, and have been contributed to by such workers as Carpenter, Hadfield, and Rosenhain.

The last of these reports, the eleventh, embodies work at the National Physical Laboratory from 1914 to 1918, the year when that Institution became a part of the Department of Scientific and Industrial Research. It deals with light alloys, the need for which the war has emphasised, especially in connection with aircraft. For this purpose the Laboratory's work has resulted in furnishing alloys of aluminium with zinc and copper, with copper and manganese, and with copper, nickel and magnesium, possessing remarkable and useful properties, such as high tensile strength at ordinary and also at raised temperatures.

Since the war light aluminium alloys continue to be studied at the National Physical Laboratory, which is the Government establishment where metallurgical research is carried out mainly for the advancement of knowledge. Here has been worked out the constitution of many important systems, binary, ternary, and quaternary, in which aluminium is the largest constituent, and the wire models constructed for the ternary alloys have proved of great value in the study of their constitution. Such questions as age-hardening have been investigated and the cause ascertained.

Systems with copper as the dominant metal have been investigated as regards their constitution, as well as the effect on their mechanical and electrical properties of known additions of other substances that may be present as impurities.

But attention is also being given to ferrous alloys for whose investigation specially pure components have to be prepared, in order to eliminate the effect of impurities of which a very small proportion may often have a marked influence on the product, and several equilibrium diagrams with iron as the main component have been worked out. Research on the more physical side includes investigations on the heat evolved during the plastic deformation of a metal, on the effect of heat treatment and composition on the magnetic properties of tungsten steels, on fatigue, and on the physical constants of metals. By the application of X-ray analysis to the crystal structure of metallic systems, Rosenhain has obtained confirmation of his conception of the nature of solid solutions.

The chemical section of the National Physical Laboratory carries out a large amount of work in connection with these researches, the investigation of methods of analysis, and the preparation of standards for the analysis of steel, as well as chemical work of a non-metallurgical nature.

Maintained by the Fighting Services since 1904 to increase the efficiency of the metals used in the manufacture of ordnance and armament, the Metallurgical Branch of the Research Department, Woolwich, increased in numbers, building and equipment during the war, and at present employs about 25 metallurgists. It has been occupied for the most part with steel,

the heat treatment of which in relation to its mechanical properties has been the subject of close study, resulting in improved gun forgings being delivered by the makers. Two main types of steel have been under consideration, those which would give a minimum yield point of about 35 tons per square inch when treated in large masses, and those at about 25 tons. As a result much information has been acquired on the properties and heat treatment of steel containing various proportions of nickel, chromium, molybdenum and vanadium. The study of the elastic properties and of the erosion of gun steel has been of importance to gunnery. The Moore adaptation of the Brinell hardness test, in which a small ball and load are used in a specially designed machine, was originally developed in the Department for testing small arm cartridge cases, and has since found many other important applications here and elsewhere.

Among other investigations on non-ferrous metals, those on 'season-cracking' of brass and its prevention, and on methods of extrusion, have been productive of useful results, and in connection with the Non-Ferrous Metals Research Association, work is in progress on the casting of brass to produce sounder ingots, on the die-casting of brass and bronze, and on the failure of lead cable sheathing by cracking.

During the war, the use of substitutes, the easing of specifications to increase output with safety, the examination of enemy ammunition, and the tracing of causes of failure and discovery of remedies provided a large field for investigation.

The other aspect of metallurgy of special interest to the State, that of minting, has a long history; from early times the need for a high and uniform standard of coinage, and the crime of debasing it, have been recognised. The difficulties that confronted the early assayers, without methods of quantitative analysis and with no fine balances, are apparent from the description of their methods, but it may perhaps be held that these needs as they became borne in on the early assayers and their frequent collaborators the alchemists, led the way to the appeal to weighing in chemical work.

As early as 928 A.D. laws were proclaimed by King Athelstan appointing 'mynteres' whose products were scrutinised at the trial of the pyx; later, in 1180, supervisors of the coin manufactured by 'moneyers' were appointed.

An official mention occurs in the reign of Edward I. of a Guild of Goldsmiths in London, which had, however, existed since 1180, in an Act providing for the assay of silver vessels by the Wardens of that craft. The earlier writings on the subject of assaying are those of Germans, of whom Queen Elizabeth brought over a number to introduce their methods and assist in the development of the resources of the country.

The course of testing seems to have been originally by means of the touchstone, supplemented much later by observing the effects of acid on the trace left by drawing the metal over the stone, the method of determination of density, the cupellation method, officially recognised by Henry II., and finally the wet method of analysis.

To safeguard the fineness of the coinage a King's Assayer was appointed in 1222, a Master of the Mint manufacturing the coin under contract, and a Warden acting on behalf of the King. A Commission, having toured the Continental mints, reported in 1870 in favour of the present organisation of the Chancellor of the Exchequer being Master of the Mint in virtue

of his office, a Deputy-Master being responsible for the administration, while the valuation of bullion and questions of assay are the duties of the Chemist and Assayer.

Many of the Mint officials have contributed largely to metallurgical knowledge. One of them, William Humphrey, in 1565 received the first patent for making brass, and a later one, Sir John Brattle, communicated work to the Royal Society shortly after its foundation on the oxidation of lead. Sir Isaac Newton when Warden is said to have himself conducted experiments on the composition of foreign coins. The melting-points of metals were studied in conjunction with Wedgwood by Alchorne, who was appointed Assay Master in 1789. From 1851 to 1870 several distinguished men of science, such as Hofmann, Graham (who in 1866 published a work on the effect of the occlusion of gases in metals), Miller, and Stenhouse, were officials of the Mint; but in 1870 it was considered preferable to conduct the chemical operations of assaying within the Mint itself, and Roberts-Austen, to whose pioneering work in metallurgy allusion has been made, was appointed. To his successor, Kirke Rose, are due many advances in knowledge of the precious metals. Thus, researches at the Mint have been directed to the investigation of metallic systems of gold with silver and other metals, the means of avoiding brittleness in gold coins, the electrolytic refining of gold, the mechanism of annealing of metals, the surface tension of solid and molten metals, as well as to improvements in the technique of the methods of assay.

Revenue.

In reviewing the influence of our science in its application to Revenue questions, it is convenient to consider historically the substances on which the State has levied duties.

In the older tariffs, fixed charges were levied on goods considered as a whole, but a time arrived when the chemist was called in; it then became possible to make an assessment on the ground of a percentage. Uncertainty prevailed, therefore, as to the basis of taxation and gross adulteration flourished until scientific safeguards were introduced.

The chief substances with which the chemist is at present concerned from the Revenue point of view are the following:—(1) liquids containing alcohol; (2) tobacco; (3) sugar; (4) tea and cocoa; (5) dyestuffs, under the Dyestuffs (Import Regulation) Act, 1920; (6) substances under the Safeguarding of Industries Act, 1921.

(1) *Liquids containing alcohol.*—On imported wine Richard I. imposed a duty, and as time went on complications were caused by the introduction of imposts for various purposes, including reprisals.

Acts were passed, as in the time of Charles II., for preventing the reprehensible practices of mixing wine and vitiating it with other substances such as cider, sugar, herbs and vitriol; it is still forbidden to mix wines of different sorts.

The difficulty of distinguishing the strength of alcoholic liquids is apparent in the older enactments, when, for example, the Legislature describes brandy as a 'strong water perfectly made imported from beyond the sea,' and it was not until the reign of William III. that they were assessed, if not in proportion to their strength, at least in some relation

thereto. The first step was their separation into 'single' and 'double' proof, a rough and inconclusive one, but accounting for the use of a term still recognised as that on which the full statutory rate of duty is leviable.

For charging Revenue the gallon was first taken as a measure in 1825, but definite alcoholic strength was not introduced as a basis until 1860; under a treaty with France, while a little later, in 1862, Parliament distinguished between wines above and below 26 degrees of proof spirit, this figure being raised in 1886 to 30 degrees.

The want of some accurate method of test had been felt, and it is interesting to follow the gropings after a method for recognising a standard strength of alcohol. Thus observations on the surface tension of spirits were employed, for Postlethwaite in 1751 described as a mark of their being up to proof the length of time elapsing before bubbles disappear from the surface of the liquid contained in a glass tube which had been shaken, but as he believed this method may be falsified, he recommended for more accurate work 'the essay instrument, or hydrostatical balance,' although for business men it would be sufficient to burn a measured quantity of the spirit in a metal cylindrical vessel immersed in cold water, and measure the remainder, which should be equal to half the original volume, if the spirits were proof. Although 'Boyle's bubble' had been described in 1675, and Moncony's areometer in 1679, the first instrument generally adopted by the Revenue in 1730 was the hydrometer of Clarke, legalised in 1787. It is complicated, however, and its temperature correction by 'weather weights' was unsatisfactory, so that Parliament gave instructions for 'proper experiments to be made.'

At the request of the Government to the President of the Royal Society, Sir Charles Blagden (Secretary) and one of the clerks, Mr. George Gilpin, undertook to make experiments on the specific gravity of alcohol and water in varying proportion. These experiments, conducted with exemplary care and ability, were reported to the Royal Society in 1790, 1792 and 1794, and formed the basis for the tables of Sikes, whose hydrometer became the sole legal instrument in 1818, and is still in use. These tables remained legal for nearly a hundred years, but in 1916 were replaced by a new and extended set, prepared under the supervision of Sir Edward Thorpe at the Government Laboratory, whence also in the same year were issued comprehensive tables of spirit strengths for use with pyknometers, as these had shortly before been legalised for alternative use in the determination of alcohol. Both of these sets of tables were founded on the definition of proof spirit contained in the Act of George III., which is, that spirit which at the temperature of 51° Fahr. weighs exactly 12-13 parts of an equal measure of distilled water. In other words, it contains 49·28 parts by weight of pure alcohol and 50·72 parts by weight of distilled water.

As these tables refer only to alcohol-water mixtures, all disturbing substances must be removed before the strength of liquids is determined by hydrometer or pyknometer. The methods of freeing spirit in commercial articles from everything but water were investigated and laid down by the Government Laboratory in 1903 by Thorpe and Holmes.

From the point of view of trade it is highly important to have free use of ethyl alcohol, while from that of the Revenue it is essential to prevent the use of such duty-free spirit as a beverage. The most effective means

to meet both requirements is to denature spirit which is to be delivered duty-free for trade purposes, and the question of the choice of a suitable denaturant is by no means easy. So long ago as 1856, the Government Chemist of the day, Mr. Phillips, proposed the addition of 10 per cent. of crude wood naphtha, and this has been found satisfactory for most purposes. The proposal was submitted to and approved by three well-known chemists of that day, Graham, Hofmann and Redwood, and this present year circumstances have necessitated the addition of a further nauseating ingredient, pyridine, in addition to mineral naphtha which was added in 1891. Mineralised methylated spirit which is sold without Revenue control, excepting that a licence is needed, contains this proportion, industrial methylated spirit 5 per cent., and power alcohol $2\frac{1}{2}$ per cent. on the alcohol.

That some misunderstanding exists as to the facilities available for the use of alcohol in commerce in the United Kingdom appears from an article recently communicated to the Ottawa Section of the Society of Chemical Industry, in which are contrasted a considerable number of compositions approved in Canada with the apparently small number legalised in Great Britain. It might be well, therefore, briefly to indicate the position, in order to make clear the facilities that are available.

Mineralised methylated spirit consists of a mixture of 90 parts of alcohol, $9\frac{1}{2}$ parts of wood naphtha, and half part of crude pyridine, together with $\frac{3}{8}$th of 1 per cent. of mineral naphtha and 0·025 of an ounce of methyl violet dye in each 100 gallons of the mixture. It is sold under licence, but is otherwise unrestricted and duty-free.

Power methylated spirit, prepared in accordance with the following formula: 92 parts of alcohol, 5 parts of benzol, 0·5 part of crude pyridine, and 2·5 parts of wood naphtha, together with 0·025 of an ounce of Spirit Red III. dye in each 100 gallons of the mixture, is also sold without restriction and freedom from duty when mixed with 25 per cent. of hydrocarbons or denatured ether or some other substance approved by the Commissioners of Customs and Excise.

Industrial methylated spirit, consisting of 95 per cent. of ethyl alcohol and 5 per cent. of wood naphtha, can be obtained for the arts and manufactures under the authority of the Board of Customs and Excise, under bond and certain not very onerous restrictions. Between three and four million bulk gallons are annually used for the making of such products as varnishes, linoleum, soap, solid medicinal extracts, ether, toilet preparations for external use, fine chemicals, photographic plates, dyes, surgical dressings, fireworks, and for many other purposes, including its use in the chemical laboratories of colleges, schools and works, and for preserving museum specimens. It is free from duty, but must not be present in an article capable of internal use, either as a beverage or a medicine.

Duty-free pure alcohol is allowed by the Board of Customs and Excise for scientific purposes to universities and public institutions for teaching and research, and specially denatured alcohol in arts and manufactures in which the use of the industrial methylated spirit is unsuitable.

The pure alcohol is allowed to colleges and public institutions for teaching and research purposes without any onerous conditions beyond the keeping of a stock account. Pure methyl alcohol is permitted by the Board of Customs and Excise to be used duty-free in arts and manufactures

under regulations similar to those for industrial methylated spirit, and is largely used in the manufacture of formaldehyde, of methyl derivatives among dyestuffs and fine chemicals, and for the purpose of crystallisation.

The specially denatured alcohol, also free from duty, is allowed to manufacturers under restrictions compatible with the safety of the Revenue, a very wide choice of denaturants being permitted. When, as frequently happens, a suitable denaturant is found in some intermediate product, or acid used, or produced during the manufacturing operations, or when the alcohol is a constituent of some mixed solvent, permission is the more readily granted for its use. An example of progressive policy in the use of pure spirit is the recent decision of the Board of Customs and Excise to allow the use of pure ethyl alcohol denatured with 2 per cent. of pure methyl alcohol in the production of insulin, without onerous Excise restrictions. It is understood that the recent action of the Board of Customs and Excise has been received with satisfaction by the Association of British Chemical Manufacturers. The quantity of pure and specially denatured alcohol used during last year was about half a million gallons.

In the case of duty-paid spirits used for medical purposes, such as the preparation of tinctures, &c., and for scientific purposes in chemical laboratories, a rebate is allowed under the Finance Act of 1920, amounting to about 80 per cent. of the duty.

While the responsibility rests on the Board of Customs and Excise of safeguarding the illicit use of alcohol, chemists have been represented on such commissions as that of the Industrial Alcohol Committee of 1905, whose recommendations led to the Revenue Act of 1906, in which the proportion of wood naphtha was reduced to 5 per cent., permission being also given for the payment of an allowance of 5d. per proof gallon or about 8d. per bulk gallon on British spirits used for industrial purposes, in consideration of the increased cost of the spirits owing to Excise restrictions.

An important alcoholic liquid that has been liable to imposts from the time of Charles II. is beer, and it was charged according to its strength or weakness as judged by the palate. After the application of science to brewing about the middle of the eighteenth century, the saccharometer was introduced, the pattern due to Bate being still in use for Revenue purposes. In 1850 an investigation made by the then Government Chemist, Mr. Phillips, and his assistant, Mr. Dobson, established a quantitative relationship between the proportion of alcohol produced in the process of fermentation and the solid matter previously in solution in the worts that had been fermented, and tables were prepared for use in determining the original gravity of the beer, *i.e.* the specific gravity of the worts before fermentation had begun. These tables, after verification by Professors Graham, Hofmann and Redwood, were employed in the Revenue service until 1914, when they were superseded by revised ones prepared by Sir Edward Thorpe and Dr. Horace T. Brown, these being rendered necessary mainly owing to the employment in brewing of many substitutes for malt unknown in the earlier days. As a rapid means for determining the original gravity the immersion refractometer is constantly in use in the Government Laboratory. This laboratory also furnished the scientific evidence for the Inland Revenue Act of 1880, which enabled brewers to use a great variety of substances for brewing.

(2) *Tobacco.*—Not long after its introduction Elizabeth imposed a small duty on tobacco, which under James I. met with not only his famous Counterblast, but an increased duty of 6*s.* 10*d.* a pound. Although Charles I. continued its repression, and the Puritans regarded its use as 'profanity,' the snuff-box became in the time of Queen Anne a necessity of the fashionable world. A regular trade sprang up in preparing substitutes from various leaves, and numerous enactments proved incapable of preventing smuggling and adulteration. It was recognised that systematic chemical and microscopic examination had to be applied to the problems arising from this adulteration, and in 1843 a laboratory, which ultimately grew into the Government Laboratory, was erected to check it, with the result that this form of fraud was almost entirely stamped out. A strict watch is still maintained on all tobacco for home use or for export, both from the point of view of absence of foreign materials and of its hygroscopic condition, as the Revenue charge is based on the latter. Chemical control is exercised over the use of preservatives and the denaturing of tobacco before it can safely be allowed out of Revenue control.

(3) *Sugar.*—In the reign of James I. the importation of sugar was already sufficiently large to make it worth while to impose a duty on it, until at the beginning of the nineteenth century this amounted to 30*s.* a hundredweight. Before 1875, when the duty was abolished, disputes had arisen as to its proper assessment on the basis of description and character. When it again became dutiable in 1901 an extended classification was based on the polariscope scale, and sugars in numerous preparations had to be determined chemically. This has raised several difficult questions of chemical procedure especially when natural as well as added sugars are present.

(4) *Tea and cocoa.*—Attempts were made in 1777 to stop the adulteration of tea with foreign and exhausted leaves and other matter, but it was not until 1875 that the Sale of Food and Drugs Act placed on the Revenue authorities the responsibility for examining tea on importation. This is done on an extended scale by the application of chemical, microscopic, and practical tests. There has been, however, no imposition of standards in the United Kingdom, as is the case in Canada and the United States.

The duty, and the drawback on the duty, on cocoa preparation has introduced chemical problems into the system of Revenue control, some of them of considerable difficulty, as, for example, those connected with the use of substitutes for the natural cocoa fat.

(5) *Dyestuffs, under the Dyestuffs Import Regulation Act,* 1920.—The importation of dyestuffs under this Act is controlled by a Dyestuffs Advisory Licensing Committee, on which distinguished chemists represent the science.

Importation of synthetic dyestuffs and intermediates is prohibited except under licence, and although the individual substances leave little room for doubt, more difficult questions come before the Government Laboratory in the case of substances containing a coloured ingredient.

(6) *Substances taken under Safeguarding of Industries Act,* 1921.—Part I. of this Act imposes an *ad valorem* duty on the products of certain 'Key' industries, of which the fine-chemical manufacturing trade is one. After the Act had passed into law, the Government Laboratory became concerned with the chemical aspect of that section which has gained

notoriety through legal inquiries involving the precise significance of chemical and technical terms. But apart from such matters, many difficult chemical problems have arisen in determining the composition of the great variety of chemical substances imported. Thus it has proved a task of some magnitude to deal with about 8,000 subjects per annum, when their examination may include the quantitative determination of the ingredients of materials such as synthetic perfumes, photographic developers, medicines, colloidal preparations, alkaloids, &c. The grade of a specified material has also frequently to be assessed, and this involves a special knowledge of its manufacture and use.

The effect of the war was generally to increase the amount of existing duties and to impose fresh ones. The former condition led to increased vigilance in the chemical control on account of the introduction of substitutes to replace the dutiable substances; the latter were imposed as a post-war condition and are described above. In connection with the war-time prohibition of exports, not only of munitions but practically of all useful commodities, the services of the Government Laboratory were required to decide as to the nature of about 20,000 substances, including cases in which the prohibited goods were skilfully disguised.

For all matters involving chemical advice the Board of Customs and Excise applies to the Department of the Government Chemist, who maintains on his staff for this section of the work a sufficient number of chemists and assistants to make the necessary investigations and deal with the chemical points at issue, as well as to carry out the necessary practical work, both in London and at several of the ports. This aspect of the work of the Government Laboratory involves a knowledge of Revenue law and precedent as well as an intimate acquaintance with a large range of chemical manufacture.

The importance of chemical control in safeguarding the Revenue is obvious. With increase in the number of subjects brought under supervision, the greater refinements and accuracy demanded, the investigation of new processes, and the amount of chemical work, the number of chemists is rapidly increasing.

Health.

The earliest legislation in respect of food dealt with articles from the Revenue standpoint rather than from that of safeguarding users against adulteration. Thus, the Adulteration of Coffee Act of 1718 refers to evil-disposed persons who make use of water, grease, butter and such-like materials for addition to coffee, 'whereby the same is rendered unwholesome and greatly increased in weight, to the prejudice of His Majesty's Revenue and the health of his subjects.' Similarly, the Tea Act of 1730 refers to the use of various materials and operations for sophisticating tea, 'to the prejudice of the health of His Majesty's subjects and the diminution of the Revenue.' The Tea Act of 1776, which deals specifically with the preparation of other leaves for use in imitation of tea, gives as an additional reason 'the injury and destruction of great quantities of timber woods and underwoods.'

Since this legislation was mainly for the prevention of fraud on the Revenue, it was left to the Crown to take such steps as were considered necessary to ascertain the purity of the articles in question. To this end

the Inland Revenue Laboratory, which was established in 1842 primarily for testing tobacco, became also the laboratory for the analysis of dutiable foods, such as tea, coffee, pepper. In this connection it is of interest to note that the Government at times sought assistance from distinguished chemists not on its staff, as when Thomas Graham, at University College, London, carried out for the Board of Inland Revenue an inquiry into the chemical means of detecting vegetable substances mixed with coffee for the purposes of adulteration. Among the early pioneers in the chemistry of food may be mentioned Dr. Hassall, who was the analyst of the 'Lancet Sanitary Commission,' and published the reports of that body under description of 'Food and its Adulteration.'

Besides the enactments with regard to certain dutiable foods referred to above, legislative action was taken with respect to bread, the Bread Act of 1822 dealing with the sale of bread in London and district, and that of 1836 with the sale of bread outside the London area. There was no provision for analytical examination of samples under these Acts, which still remain in force.

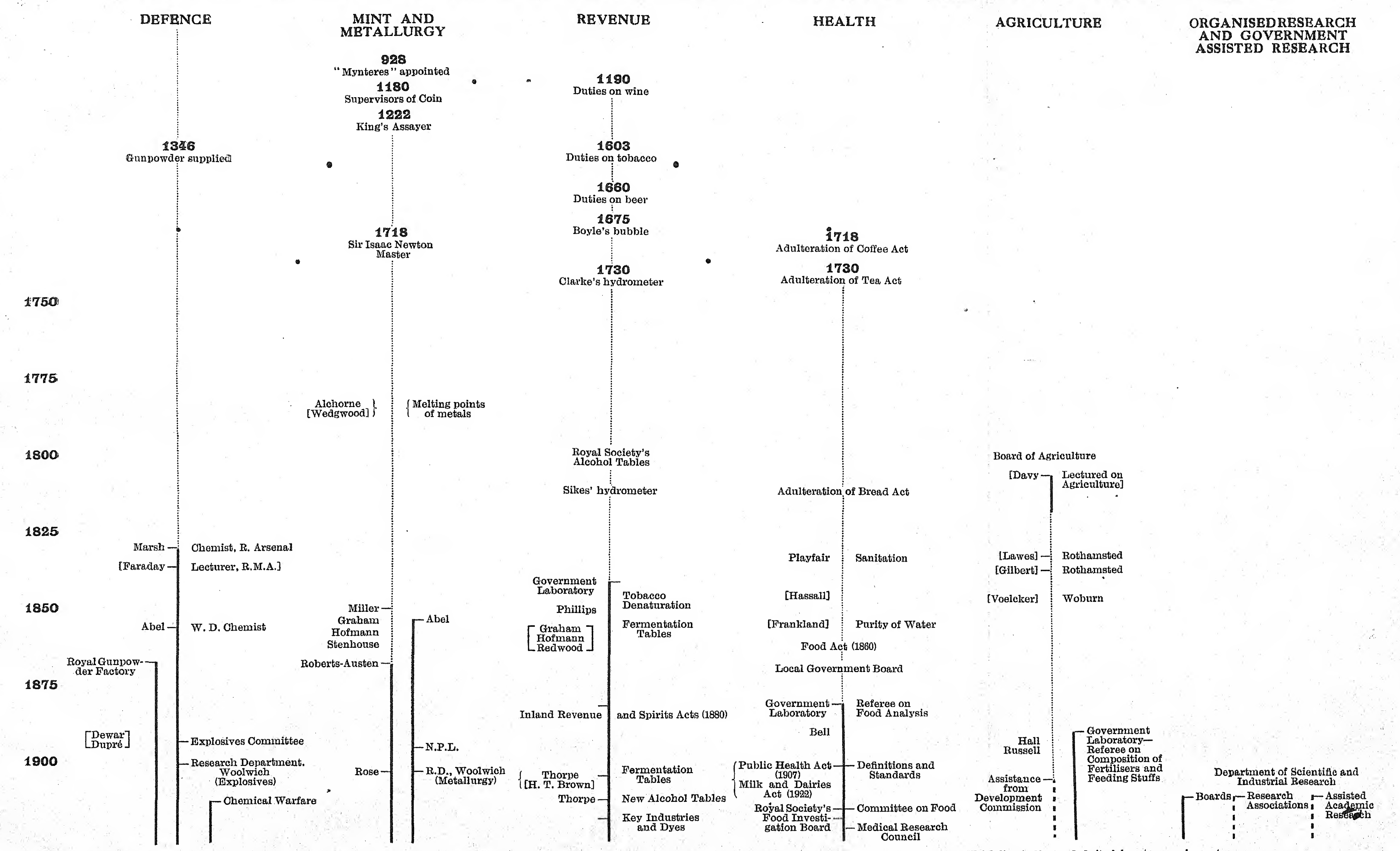
By the efforts of Lyon Playfair on matters of sanitation and the work of the Royal Commission on the Health of Towns of which he was a member, public opinion was being awakened during the 'forties to the social importance of the health of the community, a movement in which the Prince Consort took an enthusiastic part. This led to the Commission of 1869 and the foundation of the Local Government Board, through which the safeguarding of public health in England was systematically organised. From this Board and its successor, the Ministry of Health, a series of useful reports on questions of food have issued, most of which have involved chemical investigations.

In 1855 and again in 1856 a Committee was appointed by Parliament to inquire into the 'Adulteration of Food, Drinks and Drugs.' It was evident to these Committees that some provision for the chemical analysis of samples was necessary, but they made no provision for samples to be taken. This and other matters were provided for in an amending Act, which came into force in 1872. A Select Committee of Parliament was appointed in 1874 to inquire into the working of these Acts, and as a result of their report another Act, that of 1875, was substituted. By this Act the Local Government Board was given power to require evidence of competence from analysts, and the Inland Revenue Laboratory (now the Government Laboratory) was appointed as the authority to which Courts of Law could refer disputed cases.

The Act of 1875 has been amended and extended by the Acts of 1879 and 1899, and other Acts have been associated or incorporated with it, such as the Margarine Act of 1887 and the Butter and Margarine Act of 1907, the whole series being referred to collectively as the Sale of Food and Drugs Acts, 1875-1907.

The provisions in the above Acts affecting chemists may be summarised as follows: (1) the appointment of public analysts by local authorities is compulsory; (2) the Ministry of Health and the Ministry of Agriculture (when the interests of agriculture are in question) have power to step in if the local authority fails to utilise the services of the public analyst; (3) the appointment and dismissal of a public analyst by a local authority are subject to the approval of the Ministry of Health; (4) the analyst must

CHART SHOWING DEVELOPMENT OF STATE'S ACTIVITIES IN CHEMISTRY IN THE UNITED KINGDOM.



Thin dotted line indicates continuity of some Department of State. Thick dotted line indicates partial assistance given by State. Thick line indicates definite laboratory equipment.

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afford the Ministry evidence of his competence for the work. It is the practice of the Ministry to accept for such purpose the Diploma of the Institute of Chemistry, together with the Certificate of that Institute in Therapeutics, Pharmacology and Microscopy.

The position of the Government Chemist in the administration of the Acts is as follows: (1) the Acts provide that in the hearing of any complaint in a court of justice the magistrates must, at the request of either party, and may themselves without any previous request, send the reserved portion of the sample to the Government Chemist for analysis. This provision is taken advantage of in a number of cases each year, and gives rise to a considerable amount of interesting work relating to methods of analysis, the alteration in food on storage, and the figures to be taken as standards for genuine articles. The necessity for such investigation is at once apparent in the case of milk, since samples cannot under ordinary circumstances reach the laboratory before the expiry of at least three or four weeks, and the fermentation that has taken place in this time has resulted in the loss of solid matter.

(2) The Acts provide for the examination at the Government Laboratory of samples of imported tea, margarine, and various dairy products, the object being (*a*) to prevent adulterated food of this character entering the country, and (*b*) to ascertain whether it conforms to the standards laid down for such food.

It may be pointed out that there is nothing in the United Kingdom corresponding with the series of food definitions and standards which exist in some of our Colonies, and in a marked way in the United States. The main provisions of these Acts are briefly that (1) no person shall mix any article of food with any ingredient so as to render the article injurious to health, and (2) no person shall sell to the prejudice of the purchaser any article of food which is not of the nature, substance and quality demanded by such purchaser. A few definitions and standards are, however, given in the Acts, and these have been added to by Regulations under the Acts, or by Regulations made under the Public Health (Regulations as to Food) Act, 1907, the Licensing Act, 1921, and the Milk and Dairies Act, 1922. Before regulations on questions of limits have been issued, it has been customary for the Crown to institute an inquiry into the particular subject.

A brief summary of the definitions and standards thus fixed is as follows:—(1) The strength of spirits must not be reduced more than 35 degrees under proof; (2) standards have been fixed for milk, separated milk, condensed and dried milks; (3) limits have been set up for water in butter, milk-blended butter and margarine, and for butter fat in margarine; (4) the addition to milk of water, preservative, colouring matter, separated or reconstituted milk is prohibited; (5) cream must not be mixed with a thickening substance, and the conditions with regard to the addition of preservative to it have been laid down.

In its care for the purity of drinking water the State has made several enactments. It may be said that this country led the way as the result of the great work of Frankland in devising means for determining the potable qualities of water, and in pressing for pure supplies. An enormous volume of useful work was carried out by the Royal Commission on Sewage Disposal of which Ramsay was a member. This sat from 1898 until 1914, when it dissolved, having projected further work on industrial effluents

and their effect on river water, work which is just recently being followed up by an Advisory Committee to the Ministry of Agriculture and Fisheries.

The contamination of the atmosphere is a subject of concern to the Ministry of Health working under Acts from 1863 onwards. Limits have been set to the discharge of noxious and offensive gases, and the control is in the hands of a number of chemical inspectors, who have in addition carried out a large number of investigations of importance to general health and to industry. The contamination of the air in cities is watched by the Meteorological Office, which records the quantity of soot falling in different parts of the country. By such means the public conscience is being awakened to the necessity for carrying out work on the provision of a smokeless fuel, a subject engaging the attention of the Government Fuel Research Station.

Chemical control is also concerned with the question of danger to health arising in certain trades, such as that of the manufacture of matches, in which red was substituted by law for white phosphorus, with the limitation of lead in glazes, with the nature of the gases in mines, and with manufactures in which poisonous substances such as nitrobenzene and nitrous fumes are produced.

In 1900 there was a serious outbreak of sickness attributable to poisoning by arsenic, and a Royal Commission was appointed to inquire into the cases and to ascertain by what safeguards the introduction of arsenic to food could be prevented. A very large amount of chemical work was carried out in connection with this inquiry, and considerable attention was paid to the methods for the detection and examination of arsenic. Among those contributing specially to the problems may be mentioned Dr. George McGowan, the Government Laboratory, and a Joint Committee of the Societies of Public Analysts and Chemical Industry. At the Government Laboratory an electrolytic apparatus was devised in which the use of zinc for the production of hydrogen was not necessary. This apparatus has been modified by replacement of the expensive platinum cathode originally used by lead coated with mercury, which has been found to give very satisfactory results.

It was not until the end of 1916 when the war had continued for more than two years that the control of the food supply of the country passed into the hands of a Ministry of Food. In the meantime much work of a scientific nature had been done in the way of endeavouring to educate the people on food values. A pioneer in this direction was Professor W. H. Thompson, who occupied the Chair of Physiology in Trinity College, Dublin, and who became later Scientific Adviser to the Ministry of Food. He was unfortunately lost in the sinking of the Irish mail boat in which he was a passenger. Thompson communicated to the Royal Dublin Society early in 1915 an important paper dealing with the energy value and chemical constitution of foods, subsequently published as a pamphlet under the title of 'The Food Value of Great Britain's Food Supply.' The question of the food supply of the United Kingdom was receiving attention in 1916 from a Committee of the Royal Society which included among its members distinguished chemists, and at the request of the Board of Trade the Committee drew up a report on the food supply in which much of Thompson's work was incorporated. It is interesting to note that in the main the values given by Atwater in the 'Chemical Composition of American Food

Materials' were followed in the calculations. There can be little doubt that the decision of the Government to recover a larger proportion of the grain for human food in milling wheat, and to restrict the use in brewing and distilling of materials capable of use as food, arose from the suggestions put forward by this Scientific Committee.

The chemical examination of the enormous quantities of food, together with the inspection of the packing and the testing of materials used for the purpose, forwarded overseas from this country for the Army in the war was entrusted to the Government Laboratory. Chemists were established at the various receiving depots, and all goods delivered by contractors were inspected, and, if considered necessary, sampled and analysed as to their conformity with specification. The chemist reported upon each delivery before the Army authorities proceeded to issue it.

The Medical Research Council, now under a Committee of the Privy Council, deals with subjects coming within the province of biochemistry, and the organic chemist has here an opportunity for preparing substances which the knowledge now available indicates as likely to be of value in combating, for example, diseases due to parasites in the bloodstream.

Agriculture.

The connection of the State with scientific agriculture goes back to the beginning of the nineteenth century. The period from 1770 to 1820 was one of great activity in agricultural development. It was then that several of the oldest agricultural societies were formed, and the Chair of Agriculture and Rural Economy founded in Edinburgh University.

The first Board of Agriculture was formed in 1793, and it was to this Board that Humphry Davy, himself one of its members, delivered during the years 1802-1812 the courses of lectures which were afterwards published under the title of the 'Elements of Agricultural Chemistry.' Davy in his introductory remarks dealing with the object of the lectures sets out clearly what he understood by Agricultural Chemistry—it 'has for its object all those changes in the arrangement of matter connected with the growth and nourishment of plants; the comparative values of their produce as food; the constitution of soils; the manner in which lands are enriched by manure, or rendered fertile by the different processes of cultivation.' This statement sets forth the position to-day, and in the progress that has been made towards the attainment of these objects the chemist has played an important part.

Although Davy quotes the results of his chemical work on a series of grasses, no great advance was made for many years, and when it did come it was at the instance of private enterprise. To John Bennet Lawes, the founder of Rothamsted, is due the initiation of experiments which began in 1834 and have continued uninterruptedly until to-day. Joseph Henry Gilbert joined Lawes in 1843, and the association of the two was not broken until Lawes' death in 1900. The cost of this experimental station was borne entirely by funds supplied by Lawes. When Gilbert died in 1901, Sir A. D. Hall became director, and he was succeeded in 1912 by the present director, Sir John Russell.

The next experimental station in England was that founded by the Royal Agricultural Society on the Duke of Bedford's estate at Woburn

under the direction of Dr. A. Voelcker, and now carried on by his son Dr. J. A. Voelcker. The Royal Agricultural College at Cirencester was founded in 1845.

The development of the scientific study of agriculture was thus left largely to such institutions as that of Rothamsted, and to certain agricultural colleges which did not receive State aid.

The first legislative action on behalf of agriculture with which the chemist was concerned was an Act for the protection of the agriculturist against fraud from the purchase of inferior or worthless manures and feeding stuffs. By the Fertilisers and Feeding Stuffs Act of 1893, superseded by the Act of 1906, the seller of artificial fertilisers and certain classes of artificially prepared feeding stuffs was compelled to give with the goods an invoice guaranteeing the percentages of specified constituents on which the value of the article depended, and county authorities were required to appoint agricultural analysts for the purpose of checking the statements on the invoice by analysis of samples. The Board of Agriculture also appointed a chief analyst who was required to analyse the reserved samples in cases where discrepancies were of such a nature as to lead to the possibility of proceedings in Court.

It will thus be seen that, with the exception of the encouragement given to the work of Davy, the first State action was not towards development of agriculture, but for the repression of fraud. There were, however, movements from time to time in the direction of scientific inquiry into problems connected with agriculture, such as an investigation into the effect of food and breed on milk, and an inquiry into the efficiency of sheep dips, with both of which the Government Laboratory was closely associated.

No systematic educational work in scientific agriculture was attempted in Great Britain before 1909, when an Act was passed allocating annually the sum of £500,000 for 'aiding and developing agriculture and rural industries by promoting scientific research, instruction and experiments in the science, methods and practice of agriculture (including the provision of farm institutes).' Under this Act, a system of agricultural research was framed, based on university and on research institutions like Rothamsted, and linked up with the agricultural colleges. The scheme formulated enabled the Development Commissioners appointed under the Act to form new institutes as well as to extend the existing ones. Rothamsted was largely extended, and increased facilities afforded for work on Plant Physiology (Imperial College), Plant Breeding (Cambridge University), Animal Nutrition (Cambridge), Dairying (Reading), Animal Pathology (Royal Veterinary College), and on similar subjects. In many of these the chemist was essential. Another part of the scheme was the foundation of scholarships awarded to selected graduates of universities, tenable for a three-year course of research. In certain selected teaching institutions technical advisers for farmers were appointed, and researches not capable of being pursued at an institute were maintained elsewhere.

The provision of this scientific work for the benefit of agriculture is carried out by the Commissioners through the medium of the Board of Agriculture, with which policy is discussed and details arranged. It represents the first co-ordinated attempt by the State in the United Kingdom to secure a comprehensive scientific study of the problems of agriculture, and the first systematic endeavour to apply scientific method to

the development of agriculture. Results followed at once, and as an illustration it may be pointed out that in the eight years from 1912 to 1920 Rothamsted issued, in spite of the adverse effects of the war, 75 scientific papers, published eight books, and contributed numerous articles for farmers and teachers, and the Cambridge Animal Nutrition Station also published 60 papers in the same period. Other institutes also contributed to knowledge on this subject.

During the war, agriculture in this country was affected in several ways —for example, by (1) shortage of the usual feeding stuffs for cattle, and (2) shortage of fertilisers, particularly potash and nitrogen, both as nitrates and ammonium salts. At the same time there was a demand for an increased production owing to the diminished supplies of essential foods from abroad.

The attention of chemists was directed to these points. Fortunately the research institutes provided by the funds of the Development Act referred to above were in existence and available for making investigations. Thus the staff at Rothamsted under Russell gave special attention to the shortage of manures and prepared monthly notes for the guidance of farmers, while the Animal Nutrition Institute at Cambridge under T. B. Wood provided monthly notes on the uses of available feeding stuffs. In the latter part of the war, conferences were held weekly at the Food Production Department in which research workers from the institutes took part. These meetings had such value that the Ministry of Agriculture and Fisheries have now constituted an Advisory Council in Agricultural Research at which the directors of the institutes meet periodically to review the progress being made.

When the war-time requirements of nitrogenous fertilisers are considered, it is significant that the production of nitrogen in the form of ammonia showed no increase in the first years of the war, and only a six per cent. increase in 1917 over 1913. The restriction of nitrate supplies for munitions caused a greater demand for nitrogen in the form of ammonia, and it may be expected that in the future even larger quantities will be needed. The Nitrogen Products Committee estimated that the possible demand in the near future for artificial nitrogenous fertilisers for the United Kingdom would be 100,000 tons of nitrogen, or four times the quantity used in 1913.

Of the fertiliser ammonium sulphate we produced before the war five times as much as we required for our own use, but we imported also over 100,000 tons a year of sodium nitrate from Chile. During the war the importation of this salt was quadrupled and nearly all was taken up for munitions, being converted into nitric acid for the purpose of nitrating glycerine, cotton, toluene and phenol, and made into ammonium nitrate for the explosive amatol. All our explosives therefore depended on the importation of Chile saltpetre, a condition of affairs which gave rise to great anxiety, especially at the height of the submarine menace. Although we still had sufficient ammonia, there was no plant available for oxidising it to give the nitric acid required. As no sodium nitrate could be spared for agriculture, its place was taken by ammonium sulphate, of which increasing quantities were used for manuring the soil to obtain increased productivity. At the same time this salt was being increasingly used for making ammonium nitrate, so that the time approached when, in place of the ample margin before the war, a shortage of ammonia was in sight.

The claim of munitions on sulphuric acid also materially reduced the quantity of ammonium sulphate as well as of superphosphate by about 40 per cent., and chemists had to devise means for using nitre-cake in its place in the manufacture of these fertilisers.

Anxiety as to the want of capacity of the country for fixation of atmospheric nitrogen had led in June 1916 to the foundation of the Nitrogen Products Committee, the results of whose labours will be found in a massive Blue Book full of information on statistics, on processes, and on the comparative merits of methods for developing power. A staff of chemists and physicists attached to the laboratory of this Committee were actively engaged on investigations on the conditions of manufacture of ammonia by the Haber process, as well as in determining the physico-chemical constants of the gases involved. Much valuable work was accomplished both on the combination of hydrogen and nitrogen and also on the oxidation of the product to nitric acid, so that the Committee was able to recommend the erection of a trial plant in February 1917, and by October of that year the Department of Explosives Supply recommended the process worked out for adoption in a national factory, and a start had been made towards its erection at the end of the war.

This project was taken over by Synthetic Ammonia and Nitrates, Ltd., which has continued the research work and erected the large-scale plant. It is satisfactory to be able to announce that, instead of being about the only great nation not engaged in the fixation of nitrogen from the air, we have now in Great Britain a plant producing at the moment 150 tons of synthetic ammonia a week. From the point of view of agriculture as well as of national defence, this cannot fail to afford a fresh, if somewhat delayed, confidence.

The shortage of potash supplies was apparent soon after war broke out, since nearly all potash came from Germany. Attention was immediately drawn to other possible sources of supply and to means whereby the potash in stable combination in the soil might be made available. Russell at once called attention to the potash salts in the ash of sea-weed, bracken, hedge-clippings, wood-waste, and similar substances, and advised as to the best methods for utilising them. He also advised the use of lime, and in certain circumstances of sodium salts, whereby potash in the felspars and clays became available.

Numerous suggestions put forward as to possible sources of supply of potash were inquired into. In one interesting case, where a small-scale plant was put into operation under the supervision of the Government Laboratory, a good yield of potash was obtained from felspar, but the process involved the production as a by-product of so large a quantity of an inferior quality of cement that unless a market could be obtained for this there was no possibility of working the process successfully.

A source of supply that was used to a certain extent was the flue-dust of furnaces, which was found to contain a fair though variable quantity of potash. Considerable developments were made by Mr. Kenneth Chance, of the British Cyanides Co., in the direction of obtaining from the ores dealt with in the United Kingdom a large supply of potash, and an extensive scheme of operation was contemplated before the Armistice.

Another direction in which supplies became restricted was in respect of phosphatic manures. Importation of bones, mineral phosphates, and guanos,

owing to war conditions, could not be maintained, and, owing to the demand for sulphuric acid for essential munitions of war, the supply for manufacture of superphosphate was strictly limited. Hence attention was directed to the examination of the results obtained by using finely ground natural mineral phosphates and basic slag. These insoluble phosphates were found to possess a considerably greater value as fertilisers than they had been given credit for.

The shortage of food-stuffs for cattle arose partly from decreased imports, particularly of linseed, cotton seed, and grain, and partly from causes within the country, as for example the dilution of flour with maize and other cereals and the milling of the grain to obtain an increased percentage of flour for human food, whereby the quantity of milling offals was reduced. The attention of chemists was at once directed to the question of new or hitherto little used food-stuffs. For some years prior to the war the importation into Continental countries, particularly Germany and France, of valuable oil-seeds had been rapidly increasing, thus providing oils for margarine manufacture and valuable cakes and meals as food for cattle. The case of palm-kernels, a valuable source of oil and cake, is a striking one, for British West Africa exported before the war about 230,000 tons, of which 35,000 tons came to England and 181,000 tons to Germany, and a similar condition applied to copra, earth-nuts, and sesame seed. These and many other seeds began to be diverted to the British market, and the cakes or meals, after examination of feeding value, formed a useful addition to the food supplies, as was illustrated by the great increase in the manufacture of margarine.

Home supplies were also explored, materials which had hitherto been discarded were tried, and waste material from a variety of sources was utilised. In all this the work of the chemist was essential. The ascertaining of the composition of the material, of the digestibility coefficients of the various constituents, and of the feeding value of the material was the contribution of the chemist to this great problem of the nation.

Since many of the war-time expedients mentioned above were of a makeshift character, it is not surprising that they did not survive when normal economic conditions arose. Thus, when sulphuric acid again became available, the troublesome use of nitre-cake was abandoned and blast-furnace flue-dust was no longer collected. It was disappointing that the nitrogen fixed in the large surplus stocks of explosives, both in the form of nitric esters and of nitrogen compounds, could not profitably be utilised. Many of the difficulties were overcome in the case of the nitric esters by the application of a process of alkaline hydrolysis, but the attempt was abandoned on account of the difficulties which arose during process in freeing the product from poisonous impurities and in putting it on an economic basis.

The war-emergency work has had some lasting effects, of which may be mentioned the development of a process for making 'synthetic farmyard manure,' the increased use of basic slag as a phosphatic fertiliser, and the increased attention that is being devoted to the newer nitrogenous fertilisers, more particularly those produced by fixation of atmospheric nitrogen.

The lessons of the war have not, however, been entirely lost. The last report of the Development Commissioners, for the year ended 31st March, 1923, shows advance in every direction. In addition to the sum available

from the Development Fund of the Act of 1909, it was possible to make increased grants owing to the money received under the Corn Production Acts (Repeal) Act, 1921. The special fund enabled grants to be made for additional research, as, for example, the extension of the advisory scheme in connection with agricultural research, the provision of scholarships for children of agricultural workers, and the endowment of a Chair in Animal Pathology at Cambridge. In order to prevent overlapping and to secure co-ordination, the Development Commissioners are working in consultation with the Medical Research Council and the Department of Scientific and Industrial Research.

It may be said that the greater part of the work on agricultural chemistry since the war has been of a fundamental nature, the results of which have not yet become capable of translation into agricultural practice, although they may be expected to exert ultimately a powerful influence on farming.

Other Activities.

In addition to the activities that have been grouped under the respective headings, there are many others bearing on State problems which have occupied the attention of chemists.

Thus, expeditions, such as that of the *Challenger*, have been fruitful in results of chemical work. The investigations of Dittmar on the composition of sea-water and of Murray on mineral phosphates may be recalled in this connection.

For data on the chemical composition of rocks the Geological Survey is indebted to the work of Percy, Dick, and Pollard, and for work on the formation of igneous rocks to Teale, Harker, and Flett. The remarkable experiments of Sir John Hall on rock-formation at the beginning of the nineteenth century have been described in a recent British Association address. On several occasions the choice of building-stone, especially for the Houses of Parliament, has been before groups of geologists and chemists, especially with respect to the action of atmospheric impurities, and, although the causes of decay are fairly clear, its arrest still forms a difficult problem.

The difficulties in selecting colours sufficiently fugitive to prevent the removal of obliteration marks from postage and fiscal stamps were to a large extent solved by the activities of Warren de la Rue.

Investigations on such matters as the above for various Departments of State form part of the work of the Government Laboratory, which in addition, during the war, had to advise concerning the conservation of materials, the control of imports and exports by the War Trade Department, and on the nature of contraband goods.

Organised Applied Research.

In the middle of 1915, at a time when our shortage of many essential materials brought out the need for the application of more scientific methods to our industries, if we were to succeed in competition with other countries after the war, the Department of Scientific and Industrial Research was founded. It set out to assist firms in an industry to co-operate with one another and employ a staff of scientific men to solve their problems and develop their industry, to assist other Government Departments desirous of having investigations carried out, to organise

research into problems of practical utility of wide importance, and to foster the prosecution of researches in pure science. With the exception of the last, these aims can be considered as coming under the designation of organised applied research. The Department has always strongly insisted that it is this type of work only that it seeks to organise, the assisted worker in pure research being left entirely free to follow his bent.

As regards scientific policy, the Minister in charge of the Department is advised directly by a Council of independent scientific men, and these are represented also on the various Boards and Committees entrusted with the supervision of such investigations as are directed by the Department itself.

Research Associations.—From the success attending applications of scientific research in military and industrial problems during the war, the lesson was drawn that our industries in peace-time should be infused with fresh and more vigorous life by methods which had proved their worth at our time of need. Foresight in these matters was necessary, since it behoved Great Britain, no longer with the industrial world at its feet, to make the utmost use of its resources, by adopting the methods that were most efficient and solidly based on science, in order to produce material that would maintain the tradition of the excellence of British goods. While it was recognised that the most powerful chemical industries maintained efficient research staffs, it was decided to encourage separate industries to organise themselves for the co-operative prosecution of research. To the associations erected under this scheme grants, for a term of years only, and usually on a pound-for-pound basis, are made from a fund of a million pounds voted by Parliament in order to demonstrate to the industries the advantage of investigating their own technical problems, for it was recognised that many industries would have to carry out research themselves before they could properly appreciate its application.

In its last published Report the Department remarks on the continuance of these grants to the associations beyond the originally intended period of five years, as this period has proved insufficiently long for the equipment of laboratories and the effective launching of important investigations, especially during a time of industrial depression.

A very wide field is covered by the research associations. Among those that have been set up in which chemistry is important are associations for the textile industries, for rubber, leather, and shale oil, for flour and sugar, for non-ferrous metals, cast-iron, glass, refractories, and Portland cement, and for scientific instruments and the photographic industry.

As the results obtained by the associations are primarily for the benefit of their constituent members, the onlooker has a chance of gauging the chemical work carried on only from the communications which, following an enlightened policy, the management of some of them permits to be published; and as many of these are contributions to 'pure' chemistry, an example is afforded of the opportunity as well as of the necessity for work of this kind in the case of investigations undertaken primarily for an industrial purpose.

It would be impossible to review the work of the research associations for all these industries, even if the data were available, and so reference will be made only to some of their publications, including those of the

group which is concerned with the textile fibres, cotton, flax, wool, and silk, as the work published presents many interesting features. Thus there are being studied the products of the hydrolysis of cotton, with an obvious bearing on the constitution of cellulose, the chemical constituents of cotton waxes, and the action of micro-organisms on cotton fibres and fabrics. Flax, hemp, and ramie fibres are being investigated as to their distinguishing characteristics and behaviour with reagents that affect their lustre and absorption of dyes. Wool has been found to have a selective action, whereby it absorbs the alkali from the soap used in scouring, and methods have been evolved for accurately following the action in practice. Similarly with silk, a systematic study is being made of the action of acids and alkalis on the components of this fibre. In the respective laboratories the chemical and physical properties of each of these fibres are being studied and correlated for the purpose of explaining, for example, their strength and lustre, and at a recent meeting of the Faraday Society the methods and results of workers in all these fibres were reviewed in a General Discussion.

A close scientific scrutiny is being applied to the tanning of leather, and the chemical and physical changes involved, together with a bacteriological study of the process. Equally important for this industry and for that of making photographic plates is the study of gelatin, whose chemical and physical properties are being elucidated, while work of benefit to pure science has been published on the effect of light on the photographic plate.

The study of the chemistry of glass and the physical properties associated with changes in its composition is another example of work that has been reported in the literature for improvement of an industry.

The record, as has been stated, must be incomplete, but the subjects mentioned present the appearance of being valuable in the scientific study of material and process, and can scarcely fail to lead to the betterment of the respective industries.

Boards.—The Boards and Committees under the Department may be broadly divided into those which undertake the investigation of work of national importance, and those which undertake work of specific importance to Government Departments and correlate the scientific work that these carry out.

A large amount of chemical work is carried out by these Boards. The Departmental Research Boards and Committees dealing with chemical subjects are concerned with the cause of the deterioration of fabrics by organisms and light, and their fireproofing; with the changes that food undergoes under varying conditions of storage, and the constitution of fats; with the chemistry of the treatment of timber; with the survey of our coal resources and the economic usage of coal; with the production of alcohol and liquid fuel from waste vegetable matter; with the chemical aspects of the problems of adhesion, lubrication, restoration of museum exhibits; with building materials, paints, and the preservation of stone, and with the properties of several of the minor metals. For subjects of the magnitude and importance of some of these, staff and equipment have in several instances been provided on a considerable scale, and a growing number of monographs and communications to the literature issues from the respective Boards.

The Co-ordinating Board for Chemistry, like the similar Boards for other sciences, was founded for the purpose of securing interchange of information among Government technical establishments, seeing that outside interests are informed, when this is practicable, and arranging for researches not otherwise provided for. The Board carries out these duties in consultation with representatives of the Fighting Services and of other Government Departments materially affected, and with independent chemists, when departmental schemes of work are reviewed in the light of information that may be in the possession of any of the members of the Board. To this Board are referred questions of wider importance than are within the purview of any one Department, and it keeps under its consideration the development of the natural resources of the country. With further facilities for undertaking investigations, it will be in the position to extend such work and to arrange for subjects not otherwise provided for, as well as for those at present under investigation.

Assisted General Research.

Apart from the indirect help afforded to the universities by means of Government grants, direct assistance is given by the Department of Scientific and Industrial Research to research workers who may be students, or independent workers, and to important pieces of pure research. To these grants no conditions are attached ; they are given for the extension of knowledge.

One of the objects of these grants is to encourage the supply of highly trained scientific research workers to meet the growing needs of the Government, the industries of the country, and indeed of the Empire. The lack of such was felt acutely during the war, although now, for chemists with the usual qualification at any rate, the conditions have changed.

Students are given grants on the recommendation of their professor that they are a type likely to be greatly benefited by spending two years at research work after taking their degree. In this case the award is for promise and not for achievement, and the hope is entertained that the necessity for these grants will gradually disappear when university finance is on a sounder basis.

Grants are given to independent workers who have shown their capacity for research, and who are handicapped by lack of facilities which they may not be able to secure from private or other sources. Further, in the case of work of unusual importance, very substantial financial assistance may be given when it appears desirable.

In this way comes recognition of the national importance of the highest type of scientific work, and to this, of course, no conditions are imposed as to the lines on which it should be carried out.

SUMMARY.

The State's appeal to chemistry has developed through the gradual recognition of the need for the application of that science to matters relating to its preservation, its currency, its financial support, its health, its food supply, its industries, and finally to academic science. A chart illustrating this development historically is appended to this address.

In the course of this development, advantage has been taken, if sometimes tardily, of the general advance in chemical knowledge, and frequent recourse has been had to the advice of well-known chemists of the day, and collectively of the Royal Society; thus for various purposes the following chemists, as officials or consultants, have in the past afforded assistance in the solution of specific problems referred to them, or by taking part in Commissions: Boyle, Newton, Davy, Faraday, Daniell, Graham, Hofmann, Redwood, Abel, Roberts-Austen, Percy, Dupré, Playfair, Frankland, Ramsay and Dewar. If has happened in several instances that as a result of these Commissions and references to chemists some definite chemical activity of the State has emerged.

It will be convenient in this summary to review the State's chemical activities before, during, and after the war.

Before the war.

Defence.—For its defence, establishments for the production of explosives were early maintained, and when this ultimately took the form of a chemical manufacture the Government factory took the lead in devising efficient processes, while from the various State research establishments has issued during the last fifty years an important body of original contributions to the theory of explosives and to the knowledge of their properties.

Metallurgy.—The metallurgical progress of the country has always been a concern of the State by reason of its application to defence by land and sea, and close touch has been maintained with successive developments in the manufacture and use of cast-iron, wrought iron, steel and non-ferrous alloys. While the main advances in process have been made in the great iron and steel works, material contributions to knowledge in this sphere have been made by chemists in the Government service.

Revenue.—For its revenue, imposts were applied in early times, but with great uncertainty, until the charge was put on a scientific basis. Very accurate tables for the strength of alcohol were worked out under the supervision of the Royal Society at the end of the eighteenth century, to be superseded by revised ones issued only a few years ago, when, in addition, new tables were issued also by the Government Laboratory, for determining the gravity of worts before fermentation. The question of rendering alcohol unpotable, but still useful for industrial purposes, has occupied much attention. As some misapprehension still exists as to the availability of alcohol for industrial purposes, a statement has been included in which the main facilities are indicated. It was on account of the necessity for safeguarding the revenue that the Government Laboratory was primarily erected, although it now performs chemical work for all State Departments.

Health.—The three main steps with regard to public health and sanitation in this period were the forcing of these questions into prominence by Playfair, with the consequent Commissions and legislation leading to the formation of the Local Government Board and its successor, the Ministry of Health, which has many varied activities in preserving purity of air and water and protecting the workman in dangerous trades; secondly, the determination of standards for a safe water supply by the pioneering work of Frankland; and thirdly, the appointment of public analysts by the local authorities, with the Government Laboratory as referee, for safeguarding the supply of food.

Agriculture.—Science was being applied to agriculture about the end of the eighteenth century, and at the beginning of the next Davy did pioneering chemical work for the Board of Agriculture. Private endeavour is responsible for the next development, State action being limited to the prevention of fraud in the sale of fertilisers and feeding stuffs. In 1909, however, the annual allocation of a sum of money to the Development Commission for the advancement of agriculture stimulated research in a large number of institutions engaged in the scientific study of problems in which chemistry plays an important part.

Other Activities.—In addition to the chemical work reviewed in the foregoing sections, there is a variety of subjects connected with State Departments to which chemists have contributed, such as the composition of the sea, and the composition and physical chemistry of rocks and building-stone. At the Government Laboratory a large number of investigations have been conducted on matters directly referred from Government Departments.

During the war.

In all the activities described, the war requisitioned the work of the chemist, but, naturally, predominantly to meet the demands of active warfare.

Defence.—The attention that had been bestowed on the subject of propellants enabled expansion to take place with no important alteration in the technique of their manufacture, to which was adapted a new type of cordite, ultimately made on the largest scale, without using an imported solvent. For high explosives we were in much worse case, as these had not been made by the Government, and were manufactured in Great Britain only in small quantity. Their study at Woolwich led to a rapid evolution of new processes, substances, and methods of use. Thus a method was worked out for the manufacture of trinitrotoluene, and to save this substance a new high explosive, amatol, devised. This explosive, consisting of ammonium nitrate and trinitrotoluene, passed exhaustive trials and was ultimately produced at the rate of 4,000 tons a week. The production of the ammonium nitrate for the mixture was in itself a stupendous undertaking, and the methods of filling the explosive into shell and other munitions gave rise to much ingenuity. In the Research Department, Woolwich, the number of qualified chemists engaged in the study of explosives in all their aspects ultimately exceeded a hundred, while for manufacture and inspection over a thousand were employed. The ideal set before himself by Lord Moulton in 1914, to produce nothing less than the maximum of

explosives of which the country was capable, was realised, and they assumed a quality and character that caused them to be copied by our Allies, and in reliability proved themselves superior to those of the enemy.

Starting unprepared, and without the advantage of a well-developed fine-chemical industry, we were able ultimately to make a reply in the field of chemical warfare that was rapidly becoming more and more effective; at the same time, by study and often self-sacrificing experiment, protecting the soldier by the development of very efficient respirators. In this connection and in that of explosives nearly every professor of chemistry in the country and many from beyond the sea were engaged.

Metallurgy.—The enormous demand for metals for munitions and countless other war requirements led to an unprecedented concentration of the metallurgical industries on the needs of the State, and to an equal concentration of metallurgical science on investigation devoted to improvement in quality of materials for new and special war purposes. The work of the Aircraft Production Department, aided by many metallurgists and engineers, on alloy steels, of the National Physical Laboratory on aluminium alloys, and of the Metallurgical Branch of the Research Department, Woolwich, on the heat-treatment of heavy forgings and on the drawing of brass, is typical of the successful effort made in every quarter. The knowledge thus gained was disseminated in the form of specifications, instructions, and reports, and has had a great and permanent effect on manufacture.

Health.—A committee of the Royal Society had been studying food values, and were able to afford the Food Controller, when he took office, valuable data bearing on the rationing of food. They had considered subjects which shortly became of much importance, such as a better recovery of flour in milling wheat. The chemical examination of the food for the Army in the war, carried out by the Government Laboratory, employed a large staff of chemists. For the supply of many fine-chemical substitutes used in medicine and surgery, formerly imported from abroad, such provisional arrangements had to be made as the organisation of a large number of university laboratories on a semi-manufacturing basis.

Agriculture.—Effects on agriculture during the war were shortage of the usual feeding stuffs for cattle and of fertilisers. The chemists stationed at Rothamsted gave special attention to the shortage of manures and prepared instructions for the guidance of farmers; and several sources of supply of potash were exploited, including kelp, felspar, and the flue-dust of furnaces. As sulphuric acid was required for explosive work, fine grinding of phosphates and basic slag was found to be more efficient than was expected. Shortage also directed the attention of chemists to the use of little known food-stuffs, especially for cattle, and the information gained as to their feeding value was important.

Other Activities.—In many other activities in connection with the war chemists were directly involved, such as in affording advice on the conservation of materials, on the numerous questions arising from the operations of the War Trade Department, on the restriction of imports and exports, and on matters of contraband.

After the war.

The magnitude of the chemical effort, it can be claimed, was a factor in winning the war which must be reckoned as of importance only second to that of the bravery of our forces in the field. But it has left a lasting mark, and given to chemistry a value which, were it not for the rapidity with which the achievements of science are forgotten, ought to keep before the public its connection with almost every phase of activity.

Defence.—To take our subjects in the same order, we may consider some of the effects of the energy spent on the production of munitions. The intensive study of explosives and of other chemical substances used in the war has led to a more complete knowledge of their chemistry, their physical and explosive properties, and has advanced chemical theory. These advantages are not of military importance only, but are reflected in the production of trade explosives. The collected records of the Department of Explosives Supply afford examples of treatment of many problems of interest to the general chemical technologist, and not only to the explosives expert.

A further benefit was reaped by chemists in every position, from the Professor to the youngest graduate, coming into direct contact with manufacturing methods and thus gaining insight into the applications of their science. While it is true that the opportunity came to few of these to take part in the design of plant and primary choice of process, nevertheless the experience was a novel one, as it led them into the field of technology, and cannot fail to have widened their outlook. It became apparent that there was a shortage of a type of chemist which had been developed in Germany, skilled in the transference of the chemical process from the laboratory to the works scale in the largest enterprises. A chemist of this type is one who, besides having a sound knowledge of chemistry and physics, has had experience in the materials of construction used on the large scale and in the operation of the usual types of plant for carrying out the operations of chemical manufacture, and who is capable of working out flow-sheets illustrating the process, and operating plant with every regard to economy. The need for instruction in such subjects had been borne in on men like the late Lord Moulton, and as a direct result of the war-time experience of our deficiencies in this direction has arisen the movement for erecting Chairs of Chemical Engineering in some of our universities. It is to be expected that from these schools, especially where the instruction is superimposed upon a full graduate course, will emanate men who will lead the way in the application of academic science to industry.

Metallurgy.—While the interest of metallurgical science in war material has fortunately fallen to a peace-time level, State participation in the support of scientific research remains far greater than before the war. In metallurgy it is exercised through the Department of Scientific and Industrial Research, with its organisations of the National Physical Laboratory and the Industrial Research Associations, as, for example, those dealing with the non-ferrous metals and with cast iron. The State also continues to maintain efficient research establishments for the Fighting Services, but it is significant that the largest of these is undertaking industrial metallurgical research on a considerable scale, for the benefit of the

brass and other industries. State support and encouragement are undoubtedly powerful factors in the rapid progress now taking place in every branch of metallurgical science in this country, and there is scarcely any related industry which can fail to benefit.

Revenue.—Since the war the principal matters affecting the revenue are the higher duties, which have rendered necessary a further denaturation of alcohol. Improved facilities have been granted for the use of alcohol for scientific purposes and in industry; regulations have been formulated for the use of power alcohol, and duties have been established on imported fine chemicals and synthetic dyestuffs.

Health.—The food shortage during the war called attention to the nature and quantity of our food supplies, and led to further investigations being undertaken by the Department of Scientific and Industrial Research on food preservation and storage. Activity is also shown by the appointment of Committees which are working on the subject of preservatives and colouring matter in food, and on the pollution of rivers by sewage and trade effluents. A great field is open in the co-operation of chemistry with medicine in the discovery of substances suitable for the treatment of the numerous diseases now traced to parasites in the blood.

Agriculture.—So far as fertilisers are concerned, the lack of a supply of fixed nitrogen from the air which obtained throughout the war has now been rectified, and Great Britain for the first time is no longer exceptional among the nations by neglecting to provide itself with synthetic ammonia for agriculture and for munitions. Such war-time expedients as the use of nitre-cake instead of sulphuric acid for making ammonium sulphate and superphosphate and the recovery of potash from flue-dust have not survived, but there has been a gain in the further development of 'synthetic farmyard manure' and the increased use of basic slag. The present activity in research in agricultural chemistry of a fundamental character is leading to a better understanding of problems of the soil and of plant and animal nutrition, and cannot fail to be of ultimate benefit to farming.

Organised Applied Research and Assisted General Research.—Established during the war as a result of an appreciation of the contrast between the successful application of scientific method to military purposes and the want of such application to many of our manufactures, the Department of Scientific and Industrial Research has extended over a wide field. Its main activities have been sketched in the directions of State encouragement to industry to apply chemistry to its problems, of State investigation of vital problems beyond the sphere of private enterprise, and of assistance to workers in the purely academic field. In all these spheres activity is shown by the contributions to knowledge already forthcoming.

In the expansion that has occurred in the chemical sections of State Departments since the war, it is interesting to note the increase in the number of chemists that are employed. As far as can be gathered, the number of chemists working in departments maintained wholly by the State is 375 for the present year, compared with 150 in 1912, while in

establishments to which the State affords partial support, such as those under the Development Commission and the Research Associations, the corresponding numbers are 150 and 50. In addition, grants are made to 145 research students and to 11 independent research workers, involving a yearly sum of about £50,000.

From the foregoing account of the connection of the Departments of State in the United Kingdom with chemistry, it is possible to trace a gradual development and ultimately a change in attitude, in passing through the stages of compulsion, expediency, and assistance.

From motives of security the State was compelled to give heed to chemical matters involved in its defence, such as those which appertained to munitions of war, including metals used in their manufacture; it was constrained to uphold the standard of its currency; and it was obliged to secure a revenue. As a consequence, the first chemical departments were set up in connection with these activities, and from them have emanated notable additions to chemical knowledge, improvements in methods of manufacture, and specifications for Government requirements that have led to improved material becoming available for civilian use. Although mostly conducted with inadequate staff, the study of these questions, it can be claimed, proved of national advantage when the time of need arose.

In the next stage, the public conscience having been awakened by the pioneering work of Playfair, it appeared expedient to safeguard health by attention to sanitation, and, as the quality of food was unsatisfactory, to set up a chemical control. Although a start was made by Davy, a member of the then Board of Agriculture, progress in this subject passed to private enterprise, and a century elapsed before direct assistance was afforded to this important matter. Out of these activities come our present system of supervision over the purity of air, water, and food, and also the recent progress made in the application of chemistry and physics to problems of the soil.

The last and more recent stage is in the nature of a recognition that the State is under an obligation to assist science, and in this case the science of chemistry, on which so many important industries are based. It took the war to bring home the danger that, although the record of the country as regards discovery in pure science was unrivalled, its systematic application was too often left to other countries, with the result of lamentable shortages during war and the risk of many industries being ineffective in peace. A measure of Government intervention and action appeared requisite, and research became the business of a Government Department. Outside of the great firms which maintain progressive chemical staffs, the firms in numerous industries have been encouraged and assisted to co-operate in the betterment of their manufactures by the application of the methods of science, and from these associations and the organisations dealing with national problems begins to flow a stream of communications indicative of useful work accomplished. Nor is the foundation of it all neglected, for encouragement is given to workers in the academic field to follow out their ideas, whithersoever they may lead them, in accordance with the truth that 'research in applied science might lead to reforms, but research in pure science leads to revolutions.'

It is important to be able to record an advance in securing an interchange of information among Government Departments, and between their work and that of the universities, a matter which before the war was unsatisfactory, as it was mainly personal and sporadic.

And it is a hopeful sign also that, although the knowledge and appreciation of the methods and capabilities of science are still generally wanting, there have been of late signs that these matters are coming to engage the attention of those who guide the policy of the State.

SECTION C.—GEOLOGY.

GEOLOGY IN THE SERVICE OF MAN.

ADDRESS BY

PROFESSOR W. W. WATTS, Sc.D., LL.D., F.G.S., F.R.S.,

PRESIDENT OF THE SECTION.

Although Geology in the modern restricted sense of the word is over a century old, and possesses a flourishing family of descendant sciences, it is still possible to trace its immediate parentage and ancestry. The only begetter is unquestionably the mining industry, and it is to the ample exposure of rocks in mines, their condition and arrangement in the simpler mining districts, and the necessity for accurate knowledge of these districts with regard to composition, succession, and arrangement, that we owe the earliest detailed knowledge of the earth-crust in certain restricted localities.

The other parent was of more advanced years, and may be described as 'insatiate curiosity'; the natural instinct for observing and collecting odd and bizarre 'rarities' found in excavations or seen in natural rock exposures. These fossils, using the word as then employed and not in the restricted sense now usual, naturally kindled interest by reason of their natural beauty, their regularity in shape, their properties, their likeness to, and yet their tantalising difference from, the appearance of living animals and plants. It was tempting to draw inferences from their occurrence and to explain them either by marvellous operations which fuller understanding of Nature had not then inhibited, or by means of catastrophic events like those familiar in the Mosaic cosmogony.

Although much had been observed and thought out by his predecessors, it is to Werner that we owe the most successful generalisations in a mineral-bearing district; generalisations which gained a wide influence owing to the enthusiasm and eloquence that attracted students from all over the world and imbued them with the desire to confirm and spread the Master's ideas. To Werner also is due a reaction from the fanciful speculations of preceding periods with which he was so impatient that he proposed to drop the very term Geology and to substitute his own word 'Geognosy' for it, a word intended by him to separate the knowable from the unknown.

Probably there would have been less controversy between Neptunists and Plutonists had Werner committed more of his work to writing, and not left us dependent on his pupils for their versions of his views. But it is a curious fact, and one probably not dissociated from a geologist's devotion to field study, that many of those who have made great advances have either disliked the act of writing or have been unfortunate in the style of their written work. It will be sufficient to couple with Werner in this respect such names as William Smith, Sedgwick, and even Hutton, not to mention those of more recent geologists. It has not been from Smith alone that views and conclusions have had to be extracted, almost by force, and committed to writing by faithful devotees.

Yet, after all, this failing has not been without its advantages. The joy of such men is in discovery, and they are happy and contented when, but only when, they feel perfect confidence in their conclusions. If their results then get published it is with an authority and finality denied to lesser men. In the progress of their work they are apt, as in fact all of them did, to infect their friends and students with the enthusiasm that only the spoken word can arouse. And to others they have always been most generous, even lavish, in giving ideas and momentum, partly out of sheer good nature, but much more through the desire to watch the germination of the good seed that they sow broadcast and to see the harvest reaped, not by or for themselves, but for the advantage of the science whose welfare is their chief care.

During the early growth of the science, as in human families, it was the influence of the other parent that was most felt. From the earliest thinkers of Greece and Rome we have record of numberless observations and discoveries, sometimes in respect of minerals or organic fossils, sometimes of unusual phenomena in mountains or volcanoes or in the relations of sea and land, generally leading to reasoned conclusions, many of them perhaps fanciful, some even absurd, but others so sound and far-seeing that they have not been upset at the present day. Many other countries, joining the favoured ones along the Mediterranean, carried the torch forward, and in spite of the clogging influence of the vested intellectual interests of the day, the stock of knowledge gradually grew, until we find that Leonardo da Vinci was able to make as great an advance in the knowledge of the earth as he did in his own arts of painting, sculpture, and architecture.

It is true that during this period observers had a tendency to confine themselves too exclusively to one or other side of their subject, and were in the habit of reproaching one another with neglect of neighbouring branches, but even this made for progress by stimulating competition and discussion.

In spite, however, of all that had gone before, in the fields both of fact-collecting and of speculation, it will be admitted that no single man made so great an individual advance, or placed it upon such an enduring foundation, or did so much on which the future of his science was to depend, as William Smith. And it is noteworthy that the spur to his discoveries was not so much his theoretical views or even his scientific zeal, as a plain and practical issue—the finding of a short cut to speedy and accurate land valuation.

The discovery by the 'Father of English Geology' that fossils are the 'medals of creation' and that strata are each characterised by special suites of organisms, was certainly one of the greatest ever made in the history of geology, and upon it have been founded directly or indirectly almost all the later advances in the science. But for the fuller utilisation of his discoveries there were needed the artistic faculty and a wide knowledge of places and people, both of which he fortunately possessed. Thus he was able to introduce handy, crisp, easily remembered and pleasantly sounding local terms to characterise his 'Formations,' and to represent the outcrop of strata on maps which were not merely topographical but, for the first time, were tectonic also. So well did he discharge this latter function that a comparison of his general map of England with the latest production

of the Geological Survey on a scale at all comparable with it fills one with astonishment at the amount of work accomplished by him, single-handed, and with admiration for his accuracy.

It is strange that, in the amateur and official work which followed during much of the nineteenth century, so little interest was taken in the industrial application of geological knowledge which in Smith's hands had been so productive. The science had, as has been said, the 'landed manner,' and the dignity of its application to arts and industries was little appreciated. A former Director of the Geological Survey of Great Britain, Sir Andrew Ramsay, quoted with approval the saying of one of his colleagues, 'it is but the overflowings of science that enter into and animate industry.' And thus, though the scientific side of geology stood to gain much otherwise unattainable information from contact with its economic application, this source of knowledge was not fully utilised, and an air of mutual suspicion—not wholly unjustified—grew up between 'theoretical' geologists and those who applied geology to mining and other economic problems. Fortunately this feeling is passing away; the two sides have found that each is indispensable to the other, and geologists are everywhere co-operating with those whose work is connected with the discovery or exploitation of the mineral wealth of the earth-crust.

Coal.—The first branch of industry to which geology made itself indispensable was coal-mining. Geology has long been in close contact with its problems, in mapping the extent of coal-fields, collecting information as to the succession of measures and the existence and lie among them of wants, faults, and igneous rocks, tracing the extension and variation of coal-seams, and estimating the resources available; and, as seams are worked at increasing depths, and in those parts of fields concealed under thick unconformable cover of more recent formations, the work of the geologist has become more essential and increasingly productive.

It is interesting to observe the application of the 'academic' sides of geology to these more recondite problems, in unravelling tectonic complexes, in the collection of facts which may eventually elucidate the precise conditions under which different varieties of coal have originated, in applying knowledge as to the limits of the original areas of coal deposit, in the interpretation of stratification in the light of the progressive travel of coal-forming conditions geographically across the coal-producing areas, and in the stratigraphical relationship and exact mode of formation of the covering rock-systems.

It is true that the accessibility of coals when first exploited, and their distribution in seams of varying quality, led, and in the newer areas are still leading, to much waste; waste on fruitless search in the light of obtainable knowledge, in exploitation of good, thick, and easily worked seams to the neglect of poorer ones, in the non-preservation of satisfactory plans and the consequent leaving of derelict areas, in unsatisfactory drainage, and in the loss of valuable by-products. But there is a corresponding advantage to those of our generation that some exposed areas of complicated structure and many of the concealed coal-fields were left for ourselves and future generations by reason of working difficulties which it would have been premature to face in the time of easily obtained abundance.

Even to-day, in spite of improved technical knowledge, there remain

many areas in which information and inference are both scanty, and where difficulties met in working have not yet been surmounted, while there will be in the future ample scope for improved methods and inventions to deal with coal at greater depths than those at which it can at present be economically worked. There is room for much new and more precise study than has yet been devoted to the variation of coal-seams, both in the vertical direction and when traced over the wide areas of their extent. Elaborate and knowledgeable sampling, followed by new means of testing, and these again by new methods for recognition of varieties, have still to be put into practice before it can be said that we are making a justifiable and economic use of the capital reserves stored up in the rocks.

Oil.—While we blame our forefathers for their destructive and wasteful handling of the coal-fields, it is ourselves and our own generation that we must blame for serious waste of oil and the destructive exploitation of oil-fields that have been permitted. There is no economic subject to which geology has so direct a relation as the occurrence and exploration of oil-fields, and nothing in recent times has given so much employment and such valuable experience to geologists all over the world. It is the only example we have of the sudden introduction of a new source of fuel on a large scale in a late stage of industrial development, and it has already revolutionised many branches of engineering practice. The introduction and spread of the internal-combustion engine and all that this implies in space-economy, cleanliness, labour-saving, and comfort, has been the greatest engineering feature of the late nineteenth and early twentieth centuries, and it has given rise to systems and methods which mankind would be loth to abandon. The whole world is being searched to prolong the good times that we live in ; but in spite of the fact that there probably still remains a recoverable percentage in the oil-producing areas, and that there must be new fields awaiting discovery, there are already signs that the high oil-mark has been reached if not passed. But, again, it is no small comfort that although our supply of native oil, easily won and easily refined and applied, cannot last very much longer, there are abundant supplies of oil-shale still left, sufficient to take its place for very many decades to come.

Metals, &c.—Although the greater part of to-day's session is to be taken up by papers and discussions on special sides of economic geology, by those who are far more competent than I to speak on them, I cannot resist the temptation to say a few words on that side of the subject which touches on metal-mining. There is probably no subject which has been in the past more dominated by the 'practical man,' who may be defined as the most theoretical of all men, but whose theories are seldom proved and are often not susceptible of proof. The valuable information that was accessible to him has been wasted because he could not use it to the best advantage, or else it has been lost because he could or would not impart it. On the other hand, the 'theorist,' as he has been contemptuously named, has been hampered because he has often only been called in when difficulties were excessive and when the train of facts or reasoning which would have been so valuable to him has been lost.

In Britain the mining industry is so old and the mineral wealth in certain spots was so plenteous and accessible that the metal-mining geologist has had little chance. The eyes have been picked out of the

mines long ago, and in certain cases their very bones picked clean, and the country has been left in such a condition that its original state can only be guessed at, and problems of relationship, structure, and origin are past solution. Consequently it is in the countries which have not been inhabited by successive races of highly civilised peoples, or in relation to substances for which there was in the past little or no demand, that the subject has been susceptible of real advance.

Thus it is that such strides in mining geology have been made in Canada, the United States, India, South Africa, and Australia, where there has been a fair field to work upon, and where preliminary surveys have opened up the country and given an idea of its hidden resources. In no other areas of the world has the work of official surveys been watched more carefully by men of capital and enterprise, and money has rarely been lacking for development where there seem to be prospects of a fair return for it. Fortunately, too, the training of official geological surveyors has provided a type of geologist exceptionally well fitted both to prospect independently and to follow out in minute detail, and from a different view-point, the preliminary and less detailed examination which is all that is practicable in an official survey. These men have carried with them not merely competence and enthusiasm, but a thorough belief in scientific principles, an extensive knowledge of border-line sciences, and the ability to apply both principles and methods to the problems involved. In the hands of such men the surest guides are scientific principles, just as in the hands of those with 'a little learning' imperfectly understood principles are most dangerous; and as the search for ores becomes keener, and as deposits smaller and more tenuous become worth working, the need for increased knowledge of principle and for minute detail in observation steadily grows.

Fortunately, we have not yet exhausted the existing stores of highly concentrated and singularly pure ores, salines, refractories, &c., and the need is less acute than it will eventually become for much improved methods of concentration and purification. When we feel the pinch it will be necessary to call upon the chemist to endeavour to make available the abundant supplies of less pure and less concentrated materials which will remain over for our successors when we have picked out the best. This has already been to some extent effected for oil and it is beginning for coal; it must eventually be done for the still less pure sources of these two substances, for less concentrated ores and the like.

Stone, &c.—The geologist has already done much in the investigation of the qualities of building stones, plastic substances, and the materials for roofing and cement. To a large extent the materials in use are satisfactory in the air and surroundings in which they occur in Nature. But the added problems of a town atmosphere, accompanied by increased stresses in large buildings and the modern demands of the architect and sculptor, have still to be met, if our buildings are to be more permanent and our towns to present a less weather-beaten aspect than they now do. New and reliable means of testing are required, and we need a more thorough understanding of the reactions produced by impure atmospheres, and the effects of the presence or absence of protective or destructive organisms. Future investigation will react in the production of more satisfactory preservatives, and it may lead to increased production and

adoption of artificial stones devoid of the qualities which undermine the power of resistance of natural stones ; at the same time more control over colour and shaping may be obtained.

Roads.—Closely akin to the subject of building materials comes that of stones used for flagging, paving, and metalling of roads, to the provision and study of which the geologist has already very largely contributed. New problems are daily introduced as road traffic becomes heavier and as roads are required to be freer from dust and vibration. Already many waste products have come into valuable utilisation, and a wide range of road metals which can be called upon for these purposes exists in almost every country.

In the siting of roads, railways, and canals, however, geology could render much more useful service than it has yet been called upon to give. The routes that are cheapest to make are by no means the cheapest to maintain, and the geological survey of routes would very often suggest slight deviations which would be more economical in the end than when the shortest route compatible with the gradients is taken.

The princes of road-makers in the old world, the Romans, were perhaps too heroic in their dealing with gradients, but they exercised quite remarkable skill in choosing such directions as to secure the least formidable gradients consistent with the general design of their routes. Their roads were, however, constructed primarily for strategic purposes and secondarily for transport, and it was necessary to sacrifice something. On the other hand, the constructors of the coach roads were, perhaps, too sensitive to the psychology of their horses and the limitations of their vehicles, and their roads are not ideal for present-day traffic. Some compromise seems to be required between the two methods, and not the method of the Roman tempered by the cuttings and tunnels of the railway engineer. Now that we have a vehicle that rejoices in a gradient, whether for or against it, and for the first time have a means for hill-climbing at speed, it is a pity to flatten down gradients too much; and though it is legitimate and even necessary to remove dangerous crossings and curves, it should be remembered that an everlasting straight vista is as exasperating to a driver as it is heart-breaking to a horse. And if roads of this most desirable type are to be satisfactorily and cheaply maintained, it will be more than ever necessary to study routes in relation to the rocks that are traversed and the water contained in them.

Something of what has been said with reference to roads applies with equal force to other engineering undertakings, railways and canals, harbour-works, bridges, and large and heavy buildings, particularly those intended to stand for centuries. The general success of such works is ample testimony to the knowledge and skill expended upon them by engineers and architects, as well as to the elastic toleration of sites so heavily taxed ; and one is tempted to believe that a much larger amount of study has been given to geological questions in these cases than is usually admitted.

Water.—Of all engineering questions, that most closely involved with geological science is probably water-supply. So far as underground water is concerned, geologists and engineers working together have amassed a volume of fact and principle which has not yet been completely codified and rendered accessible. An unexpectedly large proportion of

the available rainfall has in many instances been obtained by successful drilling, in spite of the complication of the question by surface pollution, and in the face of many legal inanities and much charlatanry. And the extension of these methods to arid regions, as in Australia and North Africa, has brought under cultivation large areas which needed nothing but the 'striking of the rock by the rod' of the driller to make new oases in the desert, and thus render available some of the richest soils in the world.

Much the same is true of overground supplies, which have been a blessing not merely in the towns and lands supplied, but to the rivers and drainage basins regularised and protected in large measure from ever-recurrent floods and the damage consequent upon them. Although in such works geological conditions are often taken into full account, an elaborate geological survey at a very early stage would in most cases more than pay its way. Such a survey would not only give a good preliminary idea of the nature and tectonics of the rocks underlying sites of dams and reservoirs, but it would save its cost in limiting the number and in giving rational direction to the inevitable pits which must be sunk, by restricting them to the elucidation of points which the surface mapping leaves obscure. It would at the same time direct attention to the innumerable pitfalls which sites often present and would generally provide on the spot much of the requisite material for construction.

It is an arguable question whether the expenditure of such vast sums as have been devoted to the supply of large towns is entirely justified. The provision of a single supply of which large quantities are used for drinking, cooking, and industrial purposes, necessitates that the water shall be of immaculate purity, and this pure substance, the purest of all the things we consume, is employed—may we not say wasted—for flushing, washing, and a host of other purposes for which a less pure water would suffice. Surely the time has come when people could be educated up to the use of a dual supply, and this should be a commercial possibility where the area served and quantity used are really large. The experience of London has shown the very high cost of a single supply to all consumers and for all purposes, and the limits of future supply are almost in sight. It seems to be time that the problems of a dual service should engage serious attention.

Power.—Owing to the configuration and rainfall of the British Isles, and their congested population, we are apt to think of water questions in terms of supply, and, though we are using a certain amount of water for power, there is only a limited development in sight. In many other parts of the Empire, however, this is becoming a valuable asset, and nowhere more than in Canada, which is rapidly developing its resources on a very large scale. What has been said with reference to water-supply is of equal application here, for the physiographic conditions which bring about steep gradients accompanied by large bodies of water, introduce factors of denudation, transport, and deposition by the water which call for most careful selection of sites for reservoirs and works, if the all too frequent disasters are to be avoided, and if the schemes are not to be ephemeral in duration and excessively costly in upkeep.

With sources of power other than coal and water—including that of the tides—the geologist has little concern. But there has been brought

into service, at Volterra in Italy, a new source of power in the high-temperature steam from fumaroles which had previously been used only as a source of borax. Now the steam is being tapped by borings adventurously carried out, and its chief heat is employed in running great power stations, only the residual heat being given up to the manufacture of borax. This may be but the beginning of the application of a new and valuable source of power in which the services of geology will be required and from which that science stands to learn much. We are haunted by the fear that a limit will be imposed by high temperature to deep mining, while that very heat may provide energy as valuable as the material which would otherwise be mined; just as we dread the gas from certain coal seams when the gas might, if it could be exploited, give a return equivalent to that of the coal itself.

Agriculture and Forestry.—Leaving aside relations already touched upon, the connexion of geology with agriculture and forestry is through the medium of soils and subsoils, and, though the geologist seems unsuited to deal unaided with soils, his methods are those which the soil investigator must use; and soil surveys are now being carried out by agriculturists working in conjunction with geologists. This results in giving new and valuable facts and inferences for the benefit of both sciences. On the geological side it is rendering more available the facts of plant distribution, and what has been called *agronomics*, which, speaking for myself, I have always found very hard to get hold of. On the other hand, the services of geologists are likely to be of especial value in the matter of transported soils, loams, loess, brick-earths, drifts, gravels, and the like, where the conditions of formation may in many cases provide a key to their peculiarities. The same considerations apply to forestry, and here in addition well-established facts, such as the successive forest types displayed in peat-bogs, may betray principles that will be of service in practice. Questions of site, sewage disposal, and health are bound up with questions of water and agriculture and need no further notice here.

Military Science.—It will be readily admitted that geology has been of conspicuous service in connexion with military operations in such ways as the siting of camps, trenches, and dug-outs; while the minute study of the water-table in northern France during the late war was not only of value in obtaining water supplies but was of conspicuous utility in mining and counter-mining, in which exact and detailed knowledge was successfully pitted against a knowledge which was 'just there or thereabouts.'

The 'eye for a country,' the visualising of features plotted on maps and making the utmost use of them, qualities on which good strategy is founded, are the same qualities which are essential to a competent geological surveyor; and I cannot help thinking that strategic ability would reap as much advantage from a knowledge of the underlying canons of topographic relief as the geologist would from a study of the principles of military topography. It was a wise scheme to train the British Home and Overseas armies on ground similar in kind and in relief to that on which they were about to fight in France; but it should have been realised that physical causes and the resultant topographical relief differ in essential particulars in temperate and tropical climates.

Innumerable as are the services which the science of geology has rendered to man on the material side, these are at least equalled, if not outweighed, by those rendered on the intellectual side, either in the direct application of its principles to the life of mankind, or in the aid given to other sciences and the confidence engendered in such of their conclusions as can be tested in the light of geological history.

Throughout most of its range and in its more special directions, geology, like zoology and botany, is mainly an observational science. Multitudes of facts have to be observed and grouped, and as much skill is required in selecting from them the more significant and decisive as in collecting them. Experiment for the most part is of service in the criticism and verification of tentative theories; and, on the physical and applied sides more especially, it is becoming of great value. But the process of examination-in-chief, and the cross-examination in the field by a highly qualified and fully trained observer, are so exhaustive that not very much is left to submit for checking to the experimenter.

Even more than either of these two sciences is geology an open-air science, and one which calls for and imparts a love of Nature, that cannot but deepen as knowledge increases. Its most interesting work lies as a rule in the districts most attractive for other reasons. In the course of geological work the country must be thoroughly traversed, and, when possible, should be seen again and again, in all lights, under all aspects, and at all times and seasons. Hypotheses grow but slowly, and call for constant checking or verification in the field, the gradually growing ideas being an intensive spur in the collection of new facts or the re-observation of old ones, and in the comparison with like or unlike cases published or unpublished. But, as they grow, hypotheses give to their framer a power of prediction, more precise as the hypothesis is better founded; and one of the most fascinating parts of his work is the testing out of such predictions and the making of crucial observations thus needed and inspired. It is for these reasons principally that geology has earned its reputation as a fighting science. It is hard to decide just exactly when evidence amounts to absolute proof; and different observers, having reached varying stages in the completeness of their observations, may be led by the sum of them to different explanatory theories; or in the sphere of their own work they may be specially influenced by facts current there.

This seems to be the place to enter a protest against dominant ideas with regard to education and training in geology. The tendency in early education has been to squeeze out other sciences in favour of those that are called fundamental, and to suppose that, because it makes use of most other sciences, training in geology ought not to be begun until all others have been mastered. This is to go counter to the history of the science itself. Its leading methods were evolved in the early days of physics and chemistry and by men often ignorant even of such principles as were then understood. As geology has grown it has given to these sciences many problems for solution in return for the solutions received, problems which would have long waited for attention had not their geological application been urgent. Further, as the solution of such problems requires not only a very extensive knowledge but a workmanlike ability to apply both methods and principles, it is difficult to say at what

stage even the most competent scientific man, if he is ultimately to deal with all his problems himself, can be ready to begin the study of geology.

Meantime, qualities of far higher value to a geologist, which in most cases can only be acquired young, are being lost, such as the habit of close observation, the aptitude to distinguish minute resemblances and differences, and the faculty of judging tendencies, together with the instinct and patience to make collections. These propensities come very early and speedily become blunted if not exercised. I would advocate, with all the earnestness of an old teacher, that some form of earth-knowledge involving observation of facts and collection of specimens, and the drawing of inferences from them, should find a place in schools and be encouraged at the Universities side by side with the fundamental sciences. Such studies will not possess the meticulous exactitude of the others, but in this respect their tendency may be corrected by them. It will, however, bring the student into contact with realities, things as they are, instead of inaccessible, abstract conceptions, things beyond experience—such as *pure* substances, or forces acting in the absence of *friction*. It will give him the thrill of discovery and explanation, teach him that the end of science is to extract law and principle from observation and experiment, and, instead of keeping him along rigid lines to an assured and pre-obtained solution, will give him a choice of approach and accustom him to frame and test hypotheses which to him at any rate will be new and his own. Further, it will do much to teach him his own shortcomings and give him a keen incentive to acquire the very sciences which in themselves may be dull or even repulsive until he has convinced himself of their utility and necessity to his own work.

While acknowledging indebtedness to those sciences which have so generously contributed their results to geology, we feel that we have some ground for complaint that at times their votaries have not resisted the temptation to drop bombs which have exploded in our midst and produced a certain amount of trepidation and sometimes legitimate indignation. We consider that it is up to those who feel compelled to do this to acquire some knowledge of geological principles and of the lines of reasoning on which they are founded. They should recognise that a pyramid is difficult to upset, because in the process of building it the materials and structure have been carefully selected and tested by the builders. To be told after a century's search and reasoning that we must take our time bill and 'sit down quickly and write' off 80 or it may be 90 per cent. of it, ought not to have disturbed us as much as it did, not more indeed than now does the permission of the representatives of the same science to multiply our original time bill, if we like, by ten or twenty, or even more, so far as their present state of knowledge is concerned. Our answer is that we have not done the one and have no desire to do the other, so far as the sedimentary rocks at present known to us are concerned.

The geologist, however, should be, and is, the last to deprecate the application of the highest and newest conclusions of physical and chemical science to his own problems and to the criticism of his solutions of them, for it is certain that this will always result in doing much to reduce many of the barriers which retard his advance. For this reason we must welcome even so fantastic a hypothesis as that of Wegener, for the problem of the overthrust 'nappes' of mountain regions is one of our greatest

difficulties, and all explanations hitherto proposed are so hopelessly inadequate that we have sometimes felt compelled to doubt whether the facts really are as stated. But the phenomena have now been observed so carefully and in so many different districts that any real doubt as to the facts is out of the question, and we must still look for some adequate method by which the overthrusting could have been brought about. And if dozens of square miles of ground have been shifted over their foundations and away from their roots for many linear miles in the course of a single geological Period, who shall say what might not be accomplished in the course of Eras ?

Important consequences flow from the fact that the goal and expression of most geological research is the construction of a map of the area studied. To the layman who studies a country with a geological map in hand, it is hard to resist the conclusion that the map is merely fanciful ; he can see no evidence for the lines laid down or the symbols employed, and he is astonished when trenching or drilling proves their correctness at any particular point. It is difficult for him to see or to realise the cumulative force of the aggregation of minute pieces of evidence, slight differences in slope or soil, variations in quality, quantity, or luxuriance of vegetation, variations in dryness or moisture, the distribution of culture, the extension into the area of some underlying tectonic plan—the laws of which may have been worked out elsewhere, and the thousand-and-one considerations which go to make up the mind of the geologist.

It is, of course, perfectly true that the individuality of the surveyor enters not a little into the extrapolation of geological lines beyond the points where direct observation of the rocks is possible. So much is this the case, that it is feasible, from the inspection of his map, to gauge, not only the geological competence, experience, and attainments of the surveyor, but his knowledge and grasp of physiographic form, his power to see into intricate solid geometry, his artistic skill of hand and eye, and, above all, that indefinable quality his 'eye for a country' on which so very much depends.

The construction of a map has the further advantage that it grows by the alternation of periods of observation in the field with periods devoted to the thinking out of structure after each day's work and in the intervals between successive visits to the field, so that, with every return to the ground, the facts may be re-observed and lines re-tested in the light of growing knowledge. It is true that ideal observation should be so complete and exact that re-observation has nothing to teach ; but, as a matter of fact, with a map as with a book, what one takes from it is what one brings to it, clarified, improved, and extended. There should be allowed to professional geological surveyors as much elasticity as possible, so that, in addition to detailed and exhaustive primary survey, there may be frequent revision in the light of their own work and that of their neighbours. In this respect the hand-coloured form in which geological maps were originally published has an advantage over the newer, cheaper, and more consistent colour-printed maps.

Geologists should give a cordial welcome to the new aid provided by aerial survey and photography. This provides the last point of view of their areas which has been hitherto denied, though they have been in the habit of making use of the only substitute open to them, prospecting

and photographing from the highest points accessible. Many unexpected results have thus been secured in archæology, and at least as much may be looked for in geological surveys even in settled and surveyed districts, while in unsurveyed and unprospected regions its use is proving of the highest importance. Too much credit cannot be given to Canada for its enterprise in using this method for the prospecting and preliminary survey of the animal, vegetable, and mineral resources of its great hinterland by means of the aeroplane. A great saving in time and cost has thus been secured, and the method bids fair to remove the reproach levelled at the British Empire that such vast areas of it are practically unknown.

Physiography and Geography.—It is because of the variety and intensity of observation essential to geological surveying—in the course of which every acre of his ground must be traversed, and much of it retraversed—that the geologist must necessarily become a physiographer and geographer. There is a limit to the perfection of topographic maps and surveys, even when, as in the United States, there is close co-operation between the Topographic and the Geological Surveys; and it is the duty of the geologist to take note of innumerable features which have no delineation, still less explanation, on such maps. The geologist is probably the only class of person who has to traverse large areas with his eyes open, not to one class of phenomena only, but to all that can help him to decide questions of concealed structure; and he naturally seeks to supplement this by personal contact with the inhabitants, and with their written and unwritten records, which it is part of his business to interpret and explain. Nor can be confine himself to the purely physiographic aspect of his area. He is led into bypaths as a by-play, and many facts with regard to the distribution of animals and plants, and of the dwellings, occupations, and characteristics of the people, can scarcely escape his observation; neither can he shut his eyes to historic and pre-historic facts. Thus, when a geologist leaves his district, he is generally possessed of a store of knowledge reaching far beyond the strict bounds of his science.

While geologists, from the conditions under which they work, have been able personally to make individual contributions to these sciences, the most important service of geology as a whole has been the transformation of geography from a static into a dynamic science. In its earlier stages, geology discovered that progress involved the close study of the earth of the present and the application of that knowledge to explain its past changes; and the progress of that science has only intensified both the need of deeper study and the fuller application of it. To-day it is essential for geographers to be perfectly familiar with the past history of the earth in order that they may be able to explain the phenomena of the present.

The question may be summed up by saying that geology has become a physiological study of the earth as an organism with a life all its own. We can watch the geographical changes through which the earth has passed, revealed as they are in the nature and distribution of rocks and fossils. We can even discover the dry land—the actual landscape and physiographic relief itself—preserved in a fossil state, and judge from it the climates then prevailing and their distribution in distant epochs. We can form some idea of the modes of origin and dates of appearance of continents

and mountain chains, and other leading features of the relief of the crust. We are learning to read the evidence given by the interactions of igneous and aqueous rocks as to the nature of the stresses by which the structure of the crust itself has been moulded. There are, it is true, many gaps in our knowledge, but their very existence is of value in quickening and directing research in order that our history may become as full as it can possibly be made. Each advance upon the technical side of the subject, the pursuit of detailed zonal stratigraphy, the application of the microscope in so many new directions, and the broadening of the area of study, all react sooner or later in improving, refining, and extending our knowledge of earth history. They combine with the evidence of palæontology to convince us that this earth of ours is still young, active, and full of life, and that any process of 'running down' is constantly being held by self-acting checks which are putting forward to vastly distant ages 'all prospect of an end.'

Biological Sciences.—While astronomy has given us the conception of illimitable space, it has done much to destroy what has been called the anthropomorphic view of creation. Geology, on the other hand, has endowed us with an almost limitless conception of time, but has done something to rehabilitate the importance of man as the highest product yet reached in the long history of the earth.

This it has done in the main, through the intense reality that it has given to the conception of evolution. Although several authors, and two in particular, have pointed out that such a conception could not have been formed without the postulates of time and continuity of existence contributed by geology, it is hardly realised how much geological labour on the life of the earth, and on life on the earth, as summed up by Lyell and grouped and presented by him in his great work on 'The Principles of Geology,' was necessary to give to evolution a concrete and cogent application. The function of this labour could hardly be better indicated than by the position of geology as displayed in Lyell's earlier editions. The modern reader of them is continually haunted by the feeling that the author was feeling and struggling for a single missing generalisation which he failed to find; and although, in almost every branch of the subject treated, Lyell leads up again and again to the missing conception, and though the facts and inferences which he marshalled can now be seen to be marching on this great idea, he never quite succeeded in attaining it for himself. It was left for Darwin, than whom no one was more conscious of what he owed to Lyell, to see that the facts must rest on some great single fundamental principle, to realise that this principle was evolution, and to apply it to his own branch, the development of life.

Lyell had proved that the long history of the earth as recorded in the rocks revealed the operation of causes, small in relation to the earth as a whole, but persistent, the majority of them still in action. It was a further debt to Lyell that Darwin should bring in the continuous operation of small causes as the machinery operating and guiding the evolution of life.

But though the work of geologists, as summed up in Lyell, provided the starting point for the conception of organic evolution, it did not stop here. The idea of Uniformitarianism in which that work culminated was meant as a reaction against the fantastic operations postulated by the Catastrophists, and was never intended to imply that these causes in the past

were always balanced or distributed as they now are. There was in Lyell's statements nothing to indicate that denudation or earth-movement might not have been more active at periods of the past, that organic change might not accelerate or slow down, that there might not be variations in the trends of continental or oceanic development resulting in climatal and other changes, or that the very sources and intensities of energy from outside or inside the earth might not seriously vary. Only, warrant must be found for all such suppositions with regard to the earth of the past from fuller study of the earth of the present. And if we recognise the inner spirit which inspired the eloquent words of Lyell, when he had grasped that Darwin had supplied the one missing idea, we cannot fail to see that his Uniformitarianism included evolution as one of the 'existing causes' to be taken into consideration.

The physiology of the earth, however, is that of a very complex organism, and we are sure that we do not yet know all the forces internal and external acting upon it, still less their relative value and intensity, their distribution and variation in the past, or the precise records which each is capable of imprinting on the rocks of the earth-crust. But it is becoming clearer that there has been a periodicity in the stages of development of the earth-crust, and that on these great pulses of earth life there have been imposed innumerable waves of smaller cycles ; and that, on account of their interference with, or reinforcement of, one another, the simpler type of cyclic repetition which might have been looked for in the history is masked and broken and diversified by actual happenings of an infinite variety. Van Hise more than once complained of the tendency of geologists to adhere to single explanations of events, and advocated the necessity of considering the co-operation of many causes; and it may well be that in many outstanding problems such as past glacial or tropical periods, coral reefs, stages of earth movement, progression and regression of the oceans, we may find the ultimate explanation in the interaction of a number of 'true causes.'

During the long period of time comprised in the history from the Cambrian Period onwards, the slow and persistent evolution of plant and animal life went forward and left ample record in the rocks. To warrant a belief in organic evolution, we are no longer solely dependent on reasoning founded on existing organisms or on the facts of their ontogeny and distribution. As M. Marcellin Boulé says in his work on Fossil Man, '. . . . pour tout ce qui a trait à l'évolution des êtres organisés en général, le dernier mot doit rester à la Paléontologie quand cette science est en mesure de parler clairement. Les plus fins travaux anatomiques, les comparaisons les plus approfondies, les raisonnements les plus ingénieux sur la morphologie des êtres actuels ne sauraient avoir la valeur démonstrative des documents tirés de la roche où ils sont enfouis et disposés dans leur ordre chronologique même.' * Although we are only too painfully aware of the innumerable chances that conspire to prevent an animal or plant from securing immortality by preservation as a fossil, the finding of better preserved material, the more skilful preparation of it for examination, and the application to it of refined biological methods, such as careful dissection and the serial sections of Professor Sollas, are giving

* Marcellin Boule, *Les Hommes Fossiles*, 1923, p. 453.

us more complete and accurate knowledge than ever before. It may now be confidently stated that many of the most crucial links in the chain of evolving life are in our hands, that they actually lived in the past, and that their fossil forms show their relationship to their predecessors and successors. The time has come when Darwin's famous chapter on the 'Imperfection of the Geological Record,' an apology written with the most balanced criticism and unbiassed judgment, should be re-written and revised.

It is true that we seem as far as ever from unveiling the points of divergence of the great phyla, and we can but feel that the time from the beginning of the Cambrian Period onward is but a small part of the whole history of life on the earth. As with antiquarian research, each new discovery in geology, whether on the physical or the biological side, only brings these distant ages more fully into view and emphasises their modernity and their likeness to our own time. Hutton's famous dictum that he saw 'no vestige of a beginning, no prospect of an end,' is to-day more true than ever, when we regard the evidence of stratified rocks. But we know enough to convince us that within post-Cambrian time evolution has steadily proceeded from general to special, from simple to complex, from lower to higher efficiency.

In almost every subdivision of the animal kingdom, and in not a few branches of the vegetable kingdom, lines of descent and directions of specialisation have been made out, sometimes visibly operating throughout whole Systems, but more usually through smaller divisions of the record; and this in the former kingdom not only among vertebrates but among the invertebrates and even their lower sub-kingdoms. It may even be stated that in methods of defence, in food procuring, in the attainment of favourable positions and attitudes, something very closely imitating what would be expected on the doctrine of the origin of species by 'survival of the fittest' has again and again occurred.

The essence of evolution is unbroken sequence, and when we consider the extraordinary delicacy of the adjustment of life to its physical and organic environment, the mutual interdependence of life forms, and the necessity to them of such factors as favourable range of temperature, food, climatic conditions, soil, and the continuity of the 'element' in or on which they live, it is most wonderful that in the vast lapse of post-Archæan time it has been possible for life to exist continuously, and continually to evolve, throughout those long ages. And this in spite of the fact that, although the main chain has been unbroken, conditions have, in many cases, been so unfavourable that whole groups have flourished and died out, while others have become so attenuated that only a few survivors have been left, highly restricted in distribution, to burgeon out again when the unfavourable conditions were removed, or in other places where conditions have again become more favourable to them.

That life has survived continuously in spite of the vicissitudes through which it has been compelled to pass, and the frequent convergence upon it of unfavourable conditions, may well be taken to heart by those who fear that civilisation will be brought to an end by the misuse of the powers that itself has evolved. They may surely take courage and trust that the remedy for these evils will come, as it has in innumerable other cases, not from conventions and understandings that, as all history shows, will

be mere scraps of paper, but from the intensive application to them of the very science which has evolved them.

Although the geological record is and possibly will always remain incomplete, it has yet proved remarkably representative, and certain outstanding facts have been made out which are sufficient to show that the lines of organic evolution as recorded in geology are in accordance with what is theoretically probable, and with those taken by the evolution of domesticated organisms and by human arts and inventions.

1. There can be no doubt that the stages of organic evolution are correlated with and were actuated by the stages in the inorganic evolution of the earth itself. That climatic change was effective in inducing migration, and thus in sharpening the struggle for existence against both enemy organisms and changed physical environment; that extension and restriction of land and water areas in some cases brought about keener and more varied competition, change of habit or food, and in others the destruction of potential enemies and the securing of the advantages of a fair field for the survivors; and that activity of the earth-crust in such things as deposition and mountain building provided conditions for the existence of an increased range of varieties and the consequent struggle between them. If we are not allowed to say that this brought about the survival of the fit, it at least caused the destruction of the unfit.

2. It may be stated as a biological law that every locality becomes 'full' of life, forms arriving or evolving to take advantage of the special facilities offered. In consequence, resistance to the incursion of new forms, even if they are exceptionally equipped, is very great, and it is only occasionally that such new forms can make good their immigration. There are, of course, marked exceptions, but these generally occur when degeneration or overgrowth in size accompanied by neglect of means of defence have occurred, or when an area has been for so long sheltered from the wider and more general course of evolution that it has fallen seriously behindhand in the race.

The geological record gives indirect evidence of the same 'filling' of areas in the past in the extraordinary slowness with which advanced types, that have eventually made great headway, established themselves after their introduction; the earliest fishes, reptiles, and mammals are cases in point. Imperfect as the first members of these groups undoubtedly were, they must, even shortly after their introduction, have possessed considerable advantages over the older and established forms with which they found themselves in competition. In size and strength they were doubtless inferior, and probably they must have taken long periods to make good their advantage. But in all such cases the new forms went for a long period into 'retreat,' and in face of the apparent slowness of their evolution and the bitter competition to which they were subjected, it is remarkable that they overpassed the troubles of racial youth, and eventually took the place to which they were entitled in the scheme of life. It seems justifiable to believe that there must have been at least some well-equipped types which did not survive competition in these early stages, but went under with all their promise of future success. We can easily imagine that the survival of such, had it occurred, may have altered the whole course of evolution and produced a life story very different from that we know to-day, and of which we ourselves form no small part.

3. Not less remarkable than the period of 'retreat' is that of booming development which at last came to each successful modification. In this connexion we can instance the '*pleine évolution*' of the graptolites, the euechinoids, ammonoids, and belemnoids, the fishes, reptiles, birds, and mammals, each in its own time. Each slowly but surely built up its supremacy, and then wantoned through long ages as the lord of creation in its own element and in its own day. Both the period of sanctuary and the subsequent boom can be closely paralleled by the case of many human inventions and in the occupations and history of mankind.

4. But while there are outstanding cases in which a line of advance is taken that is capable of successive improvements and leads on to continuous success, there are many other instances in which the line of advance, though temporarily advantageous, has only been carried through a limited number of stages, and eventually failed either by its inherent inadequacy or by imposing so heavy a burden on the economy of the organism that it was unable to bear the cost.

The only instance I need quote, though there are many others, is the use of defensive armour, spines, plates, hooks, horns, &c. These provide an obvious method of resistance to attack, and this defensive attitude has been practised by one group of organisms after another, but always with the same disastrous result, the imposition of a fatal strain on the organism to meet renewed, perfected, and more vigorous attack. The spinose graptolites and trilobites, the armoured fishes and reptiles, are cases in point, and in the last of these instances, at least, victory rested with the acquirement of swiftness in movement, accompanied by increasing power of attack such as is given by the development of teeth or claws or both. Again and again in the Tertiary Era one group of mammals after another, before, or more usually after, the attainment of great size, has taken to some means of sedentary defence, and in every case the cost of upkeep has been too great and the group has gone under. Every time the race has been to the swift, active, and strong, and those that trusted in 'passive resistance,' in 'defence and not defiance,' have gone under in competition with those that have been prepared to face the risks involved in attack. The fact that turtles and armadilloes have survived to the present endorses rather than vitiates the principle.

Other cases of rapid decline or sudden disappearance are more difficult to account for. The waning of the brachiopods but not yet their disappearance, the disappearance of the pteridosperms, the rugose corals, the belemnoids and ammonoids synchronising with the vanishing of many orders of reptiles, will long furnish subjects for research by biologists and geologists. And it may well be that the explanation will often lie along biological rather than physical lines, such as those suggested for the graptolites; Lapworth pointed out that their disappearance—in spite of a brave effort of passive resistance—synchronised with the great development of fishes, and the assumption by them of many of the functions previously discharged by the trilobites. In other cases the explanation may be more in the direction of that given for the reptiles to be referred to later.

The rarity in the geological record of some of the stages in evolution, and the absence of others which must surely have existed, may receive some explanation from what has frequently occurred in the history of

human invention. If variants arise and are subjected to intense competition, they have no chance in the struggle for existence unless they show rapid improvement and development of the favourable variations within a few generations. Hence the numbers exhibiting each of the early stages of change will always be few and the chances of their preservation slight. Those who have tried to work out the stages in the history of an invention, for instance, will appreciate the rarity of 'missing links' and the difficulty of filling in every step towards the later perfection. These are looked upon as 'freaks' and, unless they present real and marked improvement, are never manufactured on a large scale. Their numbers consequently are few, and many of them are the victims of experiment and often do not survive the experience.

5. Perhaps the most wonderful result disclosed by a study of the later part of the geological record is the steady and unbroken evolution of brain from the earliest vertebrate animals to the present. The exceeding slowness of the process in its early stages is not less wonderful than its acceleration during the latest stages of geological history. The disappearance of so many orders of reptiles at the end of the Mesozoic Period, at the close of a long and most promising chain of evolution, indicates that there was some inherent weakness underlying the line of evolution entered upon by them, which proceeded so far and favourably that it was impossible to retrace the path. This may well have been connected with the substance or construction of brain and nerve. If so, this side of evolution has to be seriously reckoned with, and it may be that the fundamental weakness of physical as opposed to intellectual evolution brought this flourishing and well-developed group to its end.

If has, of course, been suggested by Starkie Gardiner and others that the destruction of Mesozoic life types was brought about by physical changes; but, apart from the fact that the particular changes supposed by the former did not as a matter of fact occur, the entire explanation provides a cause utterly insufficient in comparison with the potency of organic struggle against creatures better endowed with warm blood, adequate brain substance, and the activity and enterprise springing therefrom.

In spite of the evidence of acceleration as the higher ranks of animals are reached, and in spite of the extraordinary efficiency of the human brain and all the benefits to the organism it brings about, we may well be appalled by the æons which have been used up and the millions of varieties which have passed away in the production of this, the most efficient scientific apparatus yet invented or evolved.

6. But if it has taken long ages to evolve an animal capable of a broader geographical distribution than any other, with a constitution capable of withstanding the widest ranges of heat and cold, and of peopling the world from its tropical deserts to its polar wastes; and to endow him with a brain by virtue of which he has made himself master of the earth and all its living inhabitants; it has taken no less time for the evolution of the many factors without which his present success would have been impossible. To pick out a single instance, probably few things in the whole story of life have been more fruitful in effect than the appearance of the grasses in late Eocene times, followed by their rapid evolution and spread in the Oligocene and under the direction of the critical events of the Miocene Period. Starkie Gardiner in an admirable paper first drew attention to

the vital importance to the animal evolution of the world in general, and to the welfare of man in particular, of this step forward. It was followed by great changes in the insect world, by the rapid production of herbivorous mammals endowed with speed, great migratory powers, special dental and other anatomical adjustment to the new foods, and the institution in their herds of a discipline, subordination, and leadership which are almost tribal. These last qualities were rendered doubly necessary by the consequent rapid development of carnivora, and the need for scrapping passive and even active means of defence in order to secure the power, speed, and reserve necessary to follow their food harvests over great stretches of country. At the same time the habits and instincts thus brought about were those which man, by domestication, has been able to turn to his own ends. Thus at a blow, as the outcome of this stage of Tertiary evolution, there became available for mankind not only his chief plant food and drink, his luxuries as well as his necessaries, but his chief animal foods, together with his aid from the speed, strength, service, and endurance of the animals which he domesticated, and to which he assumed the position of leader of the herd.

But while with the aid just described it was possible for mankind to progress far on the road of civilisation, progress would have been stopped, and as a matter of fact was seriously retarded, until the discovery and utilisation of the solar energy stored up in the earth's crust during the Carboniferous and subsequent Periods in the form of coal and other fossil fuels. The very exceptional conditions, climatal, geographical and botanical, requisite for coal formation, occurred all too seldom in geological history, but it has so happened that few areas of the earth are devoid of coal belonging to one Period or another; and the shaping of kingdoms and dominions has been such as to include supplies of fuel in most of them. Whatever may be the main sources of energy in the future, radiant, intratelluric, hydraulic, tidal, atomic, we have been largely dependent in the past, and probably shall continue to depend for many years to come, on that portion of the solar energy stored up by vegetation, and especially on that preserved in the earth-crust in the form of coal.

But again civilisation must have been greatly hampered or driven into a different course but for the agencies which have sorted out from the medley of materials of which the earth is composed, simple compounds or aggregates of compounds, or in rarer cases simple elements, in such a form that they are available for human use without the expenditure on them of excessive quantities of energy. The concentration of metalliferous ores, salines, and the host of other mineral resources has made perhaps the most important contribution of all to the latest stage—in good and evil—attained by civilisation.

Finally, doubt may be expressed whether man could have attained his present position if he had not made his appearance comparatively soon after a period of intense earth activity, when broad areas of newly raised sediment were available for occupation, when the agents of denudation and renewal were in active operation, and when a wave of rapid organic evolution was active. And a conjecture may be permitted that human evolution itself was probably hastened by the latest climatal severity through which the earth passed, the effects of which are only slowly passing away.

Much of what has just been said may revive recollection of an old Swiss guide-book which praised the beneficence of Providence in directing the dreaded avalanches 'into the desolate and uninhabited valley of the Trumleten Thal and in sheltering from them the beautiful, fertile, and inhabited valley of Lauterbrunnen.' However, it is far from my intention to imply that 'everything is for the best in this best of all possible worlds,' but only to point out, in reviewing the long chain of events of which we see the present end-product in civilised man, that within the ken of the geologist there have been many critical stages in the earth's history when any marked change in the conditions which then prevailed must inevitably have reacted profoundly upon the development of the human race when at long last it stepped out from the lower ranks to take the earth as its rightful possession.

A review of the history and present position of geology shows that its better-known services to mankind have been in relation to the foundations on which industrial development and modern civilisation have been built —the mineral resources of the earth. These are many and various, all of them explored by geological methods. In every application of them we are again brought back to the primal essentials—water, iron, and fuel—and it is in the discovery and exploitation of these that the services of geology have been of especial value.

But in the course of the development of both the economic and the scientific sides of geology the principles discovered and elaborated have fertilised and enriched human thought as expressed not only in other sciences but also in the sphere of literature. As it has become more precise and is able to give a more accurate and detailed picture of the stages through which the earth passed during the long story unfolded by the study of the stratified rocks, it has shown that the earth, though only a minute fraction of the visible universe, has had a wonderful and individual history of its own. The keynote of this history is evolution, the dream of philosophers from the earliest times, now passed from the realm of hypothesis into that of established theory.

We are able to watch the evolution of the oceans and continents, of the distribution of landscape and climates, and of the long succession of living beings on the earth, throughout many millions of years. During these ages we see the action of the same chemical and physical laws as are now in operation, modified perhaps in scale or scope, producing geographical and biological results comparable with those of to-day. Hutton and Lyell discovered for us in the present a key to unlock the secrets of the past; the history thus revealed illuminates and explains many of the phenomena of the present.

And the outcome of it all is to endow man with a simple and worthy conception of the story of creation, and to fill him with reverence for the wondrous scheme which, unrolling through the ages, without haste, without rest, has prepared the world for man's dominion and made him fit and able to occupy it.

I desire to express my thanks to Mr. G. W. Lamplugh, Professor E. W. MacBride, Professor W. G. Fearnsides, and Mr. G. S. Sweeting for kind assistance in the preparation of this address.

SECTION D.—ZOOLOGY.

CONSTRUCTION AND CONTROL IN ANIMAL LIFE.

ADDRESS BY

PROFESSOR F. W. GAMBLE, D.Sc., F.R.S.

PRESIDENT OF THE SECTION.

'" But what was the creature like?" I asked. "What like was it? Gude forbid that we suld ken what like it was! It had a kind of a heid upon it—man could say nae mair."'

R. L. S.—*The Merry Men.*

If I were asked to point out the main change in zoological thought since the last meeting of this Association in Canada, I should venture to say that zoological problems have become problems of control, and that control, from implying mere restraint, has come to mean 'quickening.' The being, well-being, and becoming of the animal in its world are no longer problems of statics, but of dynamics. The fabric of the animal body characterised by those traits and that orderliness that are revealed by genetic analysis is no longer regarded only as a link in the chain of organic affiliation, nor as a fact simply, but as the balanced result of controlled becoming or development. The factorial hypothesis and its corollaries convey this impression strongly. The results of ecological analysis, meagre as they are as yet, point to the same conclusion. Experimental morphology may be summed up in the word 'regulation.' Animal physiology shows the same dominant tendency. The results of tissue-culture show the existence of a process which enriches the body by enforcing it. The infinitely varied animal fabric appears to be the exquisitely balanced individual expression of processes that quicken and restrain.

This change from the older thought of the animal as a mellowed, balanced product of changes under stress, has come from the renewed hope of understanding the natural problem in the new light of experimental analysis. If to succeed is to come up from below, the actual animal life that succeeds must be but a fraction of the submerged recessive life that experiment reveals. These recessives when artificially bred are no mere cripples, nor disconnected with the evolution of normals. They show us something of the depths of animal nature, and help us to realise that but for the grace of organic regulation we should be even as they. But the study of such analysis as a branch of zoology leads to an even more striking result. Not only does it reveal the existence of these sub-normals, but also it accounts for the defection of certain expected offspring. There are non-viable combinations of living substances. These entering the egg that should by expectation produce a male, render the egg incapable of

development. That family will be one of daughters only. The existence and the control of lethal factors is one of the most significant discoveries of the underworld.

It is with the results of one branch of this experimental study that I wish to deal. For several years experimental morphology has been actively pursued by zoologists in Europe and America. For the most part the egg has been selected as the natural point of departure, and the construction of the embryo or the development of the egg and of its parts has yielded results of great interest, though the search for a principle of organisation has not yet suceeded. To the developing organism it would seem to be all one whether it builds with one egg, with two eggs, or with a piece of an egg. (1) If there be any preformed or self-determined 'organisation,' it may be shattered to bits without prejudicing the appearance of a normal embryo. The nuclei of the segmented egg may be shaken about as a bag of marbles, yet there will still remain the capacity for normal differentiation. It is therefore not surprising that there is as yet no unanimity of interpretation. Some investigators seek the explanation of development in an innate 'organisation,' thereby postponing by a process of infinite regress the attack on the problem. Others assume by an unconscious *petitio principii* the very problem they set out to solve. Others take refuge in a metaphysical solution, and lately the problem of 'organisation' has been regarded as an ultimate category that stands beside those of matter and energy. (1)

Experimental zoology is a young science, and it is unlikely that we have reached Ultima Thule. Rather than regarding our position as one with our backs to the wall, I would ask leave to consider the report of the advance under the leadership of Professor Child of Chicago that has entered new territory. Instead of attacking the problem of the development of the organism from the egg, Child has long been working at the 'regulation' of regeneration and organic development. From his analytical studies (2) and (3) he has arrived at certain conclusions that have far-reaching consequences. Though based on the behaviour of the lower Invertebrates and Vertebrates, these conclusions have already proved of wide application. I believe I am right in stating that no more fertilising biological idea has been disseminated in the last ten years than Child's hypothesis of metabolic gradients. It has captured the imagination of the younger generation of zoologists and is exercising an increasing influence upon them.

The Individual considered as a Reaction System.

It is no easy task to express the principles of Child's theory of the organic individual without reference to fundamental questions on which differences of opinion prevail, and about which our knowledge is incomplete. Perhaps the best way is to give a concrete instance taken from the freshwater Planarians, those highly organised 'animated pellicles' that divide by spontaneous fission. This process is initiated externally by a transverse constriction far down the parent body, but without any morphological distinction at this region. The tail-end after separation develops a new head, brain, eyes, and other organs. The head-end develops a new tail, and the process is eventually repeated. On turning up a stone in a stream running through limestone country one can find certain species of Planaria actively engaged in multiplication by this method.

Child's work consisted in applying methods of physiological analysis to this well-known process. He found that before any external sign of constriction had appeared, the intact and apparently single individual showed a hump in the curve exhibiting the rate of chemical change in its tissues, when tested from head to tail. The maximum rate of change occurred in the head region, and then fell off gradually to rise again to a lower peak before the caudal fall. The site of the second, smaller peak was the site of the future constriction, and of the future head of the coming daughter.

From this, and a large number of other experiments, Child concluded that the head of the parent exercised a variable degree of dominance over the subordinate individual that is represented by its own posterior end. External features were no longer the criterion of individuality, but merely the final expression of the physiological relation of dominance and subordination. The nervous system was but one expression of the embodiment of the dominant region (the brain) and of the track (nerve-cords) along which this region exercised its sway. This sway diminished in intensity with the length of the cords or distance from the dominant region, and it was this gradation of the influence of the 'head' on the 'body' according to distance that Child expressed as the 'metabolic gradient.' When the intensity reaches a certain minimum, those portions of the basal region whose potential is rising may assert their own hitherto suppressed individuality. They become almost physiologically isolated from the dominant region. The further conclusion therefore arose, that what we are accustomed to think of as an individual multicellular being becomes, when interpreted in the dynamic way, a composite being. The intact Planarian is only prevented from displaying its constituencies by the dominance of the head, but a number of circumstances may interfere with the dominance. As the head by growth of the body becomes removed from the tail region, the intensity of its influence wanes. If the conductivity of the channel of influence falls, the same result ensues. Again, should the tail become the seat of growth, or assert its independence by increase of size or in other ways, then the influence of the head is negatived. In all cases the head action is positive and not merely inhibitory. In all cases the basal action on the head is not positive, but indirect or inhibitory.

There are two special assumptions deliberately made by the author of this conception of organic individuality that require emphasis. The first concerns the independent nature of the apical region, the second the use of the term 'metabolic gradient.' The assumption with regard to the first is that the head or apex expresses the most intense and most intimate relation between the organism and its environment localised at one pole. Here the two are really one, and the head is the expression of this fact as a physiological, morphological and historic process. The other assumption is based on the physical basis of life as the seat of chemical changes and chemical correlation in which it is impossible to distinguish qualitative from quantitative effects, and asserts, that controlled alteration in the rate of change (for example of oxygen consumption) along definite gradients is the main 'cause' of that structural and chemical correlation that we call the base. The head or apical region is thus, in a derivative sense, self-determined. It is the animal at its highest; and as these largely

self-determined changes appear always to lead in animals to the formation of a central nervous system if they go far enough, the conclusion is reached that the nervous system is the final expression, both in arrangement and in mode of action, of the system of metabolic gradients.

A corollary of great importance can be deduced from the case of the Planarian. The degree of individuality of the daughter is a measure of the loss of control of the head-end, a not unfamiliar phenomenon. As this occurs, the daughter becomes more and more physiologically isolated and her metabolic processes proceed at a faster rate. Hence physiological isolation is a fundamental factor in asexual reproduction.

The Development of the Frog Egg as a System of Gradients.

In the light of this conception of the individual being as a reaction-system, we may now take the unfertilised ovarian egg, say of the frog, as a primary individual. It possesses an axial gradient. One pole is the region of highest metabolic rate determined by the relations of the egg to the maternal tissues and the other external agencies. There is evidence that, from this apical pole, chemical change proceeds in waves of decreasing order of intensity through the protoplasm towards the opposite or basal pole. Though there may as yet be no visible structural change in the colloidal medium, yet the factors that produce the first visible change are there. Differentiation on this view is the expression of chemical change along the gradient. The cell or ovum is in fact a creature 'with a kind of a heid upon it—man could say nae mair.'

The changes that ensue during the maturation of this egg or primary individual are too involved, and too familiar, to zoologists for me to enumerate. The little sphere, still without visible differentiation, becomes a stratified power-station. The apical pole remains chemically active, the basal pole accumulates stores of potential food and energy. The whole globular microcosm becomes enclosed in a non-permeable membrane, and is shut off as a closed system from the outer world. If only one of its extruded polar bodies returned; if only something could break this too, too solid envelope; if only some messenger from the outer world, some Orpheus could visit the cold Eurydice, then development might begin. And it so happens. In the natural sequence, Orpheus—the spermatozoon—is the winged key that unlocks the imprisoned one. He casts a shadow—the grey crescent—that heralds the advent of the new gradient, the one that takes sides, and that prophetically unseams the germ from the nave to the chaps, that separates the right side from the left. As if to justify the use of emotional language, the germ at that moment of release takes an explosive breath as though the crisis were over. It will never take a deeper one. The process of development is begun.

The first trace of the embryo is the apical region or brain, formed as part of that region of greatest metabolic activity known as the dorsal lip of the blastopore, or the 'differentiator.' (4) This region provides the three co-ordinate lines or 'metabolic gradients' along which the main features of structure are elaborated—the primary gradient along which the central nervous system forms; the secondary gradient for the axial organs; and the transverse gradient along which the lateral organs are developed.

The fate of the cellular material with which the differentiator deals depends not on their pre-determined nature but on the changes they undergo in passing to their final place in the organism, and to the company they keep when they get there. So far as their fate is concerned they may say with Hamlet 'the readiness is all.' In the hands of the three co-ordinate gradients that radiate from the 'differentiator,' it matters nothing whether the cells they hand on to build the back or the side are those naturally presumed to fit the part. Cells that would under normal circumstances form skin cells on the outer surface, and that lie outside the reach of the differentiator, will if grafted into it become kidney-tissue, muscle-tissue, or gut-tissue. And the converse is true. Tissue of the differentiator itself, presumably destined to become kidney or muscle, may be grafted into the wound left in the skin by the previous excision, and there it will become skin. So the surface tissue that would become brain if left alone will, if grafted into the differentiator, become intricately involved, and after travelling inwards and forwards find itself transformed into the likeness of those with which it is now a companion in function. With increasing zest we may repeat Huxley's great metaphor concerning the cells of the early embryo: 'They are no more the producers of the vital phenomena than the shells scattered along the sea-beach are the instruments by which the gravitative force of the moon acts upon the ocean. Like these, the cells mark only where the vital tides have been and how they have acted.'

The events that I have briefly described constitute the prelude to two other phases through which the life of a multicellular animal passes. We may call them collectively the indeterminate, the determinate, and the integrated phases. During the first, the three waves of chemical activation assort the cellular material along the axis of the body and next determine irrevocably its fate as organs of the individual. This period begins in the frog with the closing of the blastopore and of the neural groove. From now onwards the evolution of the organs proceeds from determined beginnings impressed upon the constituent cells by their relation to each other and to the gradients. Remove the rudimentary organ from its normal position—the heart, the kidney, and the brain—and it will complete or at least continue its evolution even in the solitude of a moist chamber. But under normal circumstances this phase of organic determination leads insensibly to that condition of full and inter-related activity that we may call integration. The muscles may be able to develop apart from the nervous system, but without organic contact with that controlling system they cannot function. The kidney may exhibit characteristic complexities of origin and evolution without the aid of humoral or hormonic influence, but it cannot function apart from these. The primary factors of life—the metabolic gradients—are supplemented by new structural factors and new chemical factors, and together constitute personality.

Meanwhile, the inevitable price, senescence, is paid for advance. The stream of animal life, unlike its prototype, sedimenting most elaborately where it runs most strongly, is running down. Stability of construction brings the penalty of diminished dynamic activity, and the advent of puberty marks for many animals the shadow of the fell sergeant. But life has still its reserves, or at least one means of continuing the life-cycle in its descendant, if not in its undivided personality. In those lower

animals of ponds and streams, the Planarians, the act of procreation can be both naturally and artificially checked, and a return to a less highly organised state can be induced. In a similar way the act of sterilization induces fresh vigour in some of the higher animals. Finally, in many animals the body undergoes periodic retrograde evolution, renews its youth, returning to an undifferentiated state in which it passes the winter with heightened powers of resistance, and on the advent of spring redevelops its organisation.

Evidence for the Hypothesis of Metabolic Gradients.

(*A*) *Axial susceptibility.*

The evidence for these far-raching conclusions as to the nature of the living organism is partly direct and experimental, and partly indirect and observational. The direct evidence has been drawn from experiments by Professor Child and his school on Protozoa, Coelenterata, Planarians, Liver-flukes, Annelids, Echinoderms, Fishes and Amphibia extending over about fifteen years. Recently Dr. Shearer (5) has repeated these experiments on the chick and on earthworms, with results entirely confirming the conclusions of Child and his pupils. A critical review of the evidence has recently been published by Child and Bellamy (5*a*).

The first class of evidence relates to axial susceptibility to the action of toxic or narcotic substances. When immersed in, for example, a weak solution (0.001 mol) of potassium cyanide in well-water, the 'head-end' of the whole animal or the apical pole of the egg is the first portion of the body to undergo disintegration, and this is followed by a succession of stages during which the process slowly spreads downwards. In general, the susceptibility-curve plotted on the basis of time-ordinates against these stages as abscissae, shows a much sharper fall for young than for older animals of the same species if the solutions are above a certain degree of concentration. If very dilute solutions are used, the opposite result is obtained. Immunity is gained more rapidly by the young than by the old. These results may be explained as due to the action of the cyanide on the oxidation-process and possibly also on the physical character of the colloidal protoplasm. The important point is the definite relation of disintegration to the animal's axis. The 'head-region' or the apex of the egg disintegrates first and the basal region last. The evidence therefore tends to show that the susceptibility gradient is evidence of the existence of a metabolic gradient.

Estimations of this kind have been made by the use of a large number of narcotics and poisons and the results have been confirmatory. More recently, other methods of testing the presence, course, and strength of these gradients have been devised. Dr. Tashiro (6), for example, has applied to the nerves of the body an exceedingly delicate test (the Tashiro biometer) for the estimation of carbon dioxide in minimal quantities, and has shown that a gradient exists following the direction of the impulse along the nerve. Again, Child himself, and later Shearer, have demonstrated the presence of axial gradients in starfish and chick respectively, by the use of acetone and other substances, which are precipitated in the tissues of the living developing animal by oxidation, thus giving an ocular demonstration of the track of the primary gradient. Unquestionably

the development and application of biochemical methods will indefinitely increase the weight of this testimony, but the main thesis appears to be established, namely, that there is direct evidence of the presence of a primary metabolic gradient along the major axis of the body.

The indirect evidence is more easily appreciated by the general body of zoologists, and it is of the greatest interest. If the value of a hypothesis consists in the number of phenomena that are subsumed under it, then the gradient hypothesis on morphological evidence alone may take high rank. Old-established facts acquire new meaning.

The general succession of cellular events in animal development shows that the fertilised egg has a radial or bilateral symmetry before it exhibits cell division. Normal and experimental evidence point clearly to the conclusion that the first act of morphogenesis is the establishment in most animals of the head end, and in Coelenterates of an apical region. This is followed by the development of the dorsal surface in Vertebrates, and of the ventral surface in most Invertebrates, determining in each case the foundations of the nervous system. Simultaneously the lateral organs are laid down usually in the form of 'segments,' the outer part of which remains more embryonic and plastic, whilst the inner part, abutting on the axis of the embryo, undergoes more rapid and elaborate morphogenesis. The whole process of the gradual establishment of the primary rudiments of bodily structure in the embryo is not only consistent with the theory of gradients, but receives (perhaps for the first time) a rational 'explanation.'

(*B*) *Regeneration.*

Perhaps even more suggestive than the facts of individual development are the conclusions of experiment, both natural and artificial, upon the regeneration of animal organs and tissues. The main facts as to the extent and occurrence of the faculty for renewal of lost parts by animal tissues are well known, and need not be traversed here, but there are some special cases that are little known, and that form a test of the validity of the gradient hypothesis. Moreover, as this view grew out of the consideration of data given by the regeneration of animals, it is appropriate that this large body of analytical work should receive mention.

Child's work, and that of his pupils, has shown that in certain freshwater Planarians, only experimental difficulties set a limit to the minimal quantity of the body that will regenerate the whole. If and when these difficulties are overcome, it is probable that a single isolated cell of many of the lower animals may be induced to regenerate the whole, as is the case in many plants. We are only at the threshold of these inquiries, and the progress of tissue-culture, which is now being actively pursued, will undoubtedly open up new ranges of control over the technique of physiological isolation. It will be remembered that H. V. Wilson and J. S. Huxley (7) have shown that from the artificial fragmentation of a sponge or hydroid, new individuals arise. From a few of those fragments—sheddings composed of cell-groups, and even a few isolated cells placed in suitable conditions—there arises by cellular conjunction a small amorphous mass, which acquires polarity and differentiation, and forms a new sponge or hydroid, recalling the reconstitution of 'an exceeding great army' in Ezekiel's vision of the valley of dry bones. We seem driven to the conclusion that every cell of these animals only develops a portion of its potentiality when actively

functioning as a part of the whole, and that each cell has in addition the opposite faculty of dedifferentiation—of becoming young and resistant at the same time. When this rejuvenated cell develops either singly or in company with other dedifferentiated cells, the resultant in either case exhibits a new metabolism and a new orientation, giving rise to an organism with typical arrangements of dominance and subservience of parts, such as characterise all normal animals.

The morphology of fixed colonial animals such as corals acquires fresh interest when considered in the light of this principle. Wood-Jones (8), as Child has pointed out, has found from a study of living Madrepora under natural conditions, that there is an apical radially symmetrical zooid at the top of the stem which give rise by budding to bilaterally symmetrical lateral zooids. These, however, do not bud off others so long as the apical zooid is present and active, until by growth of the whole 'shoot' they become separated by a certain distance from the dominant apex. When that occurs, one of them becomes transformed into a radial member, puts out lateral zooids and becomes a new apex. If the apical shoot and stem are removed, several branches may arise by transformation of bilateral into radial reproducing zooids. The whole process so strikingly recalls the fundamental relations of dominance and isolation leading to organic reproduction in animals and also in plants that Child does not doubt the general applicability of the principle to organisms in general.

(C) *Independence of the Apical Region.*

One of the most striking pieces of evidence on the subject of regeneration is the work of Ivanov on certain sea-worms, Spionids and Serpulids. Unfortunately, the greater part of the work (1912) is in an inaccessible Russian dissertation (9), but the first part of it appeared in 1908 as a continuation of his earlier researches on *Lumbriculus*, a fresh-water worm. In order to make the results clear, reference must be made to Ivanov's division of the Annelid body. By reason of certain peculiarities of the mesoderm of the anterior segments, he accounts as cephalic, or, as he later calls them, 'larval' segments, not only the prostomium and peristomium of zoological nomenclature (*i.e.* the apical and sub-apical segments), but those which follow, so long as they possess certain mesodermal characteristics. The rest of the body he calls 'post-larval.' This post-larval body is specialised in Serpulids into a thoracic and an abdominal portion. If now 'the head' or three larval segments of Spirographis be removed, the process of regeneration is no simple or direct operation, but resembles, to a remarkable degree, the embryonic development of these segments; whilst the regeneration of the body-segments proceeds in a different way, but also along the lines of the embryonic development of that region. What, however, chiefly concerns my argument is the establishment of a new head, not by morphollaxis (dedifferentiation followed by reconstruction on a new type), but by the appearance of an apical plate typical of the trochosphere stage, of pre-oral antennae (which have disappeared from the Serpulid trochosphere), and of the cerebral ganglia by thickenings that correspond to the ciliated pre-oral bands of the trochosphere. The interior of this dedifferentiated thoracic end of the decapitated body is now filled by immigration of ectoderm cells that assemble in three

groups or segments, one of which gives rise to the corona so typical of Serpulids. In the meanwhile, the posterior part of the body is reconstituted into thorax and abdomen.

It is most desirable that these results should be fully tested on fresh material, but taken in conjunction with the work of Allen on *Procerastea* (10) and of the many workers on *Lumbriculus*, they point to the special nature of the apical segments of the body. Allen has shown that each batch of four or five segments taken from different portions of this Polychaet reorganise the whole, in such a manner, that the initial segments occupy the same relative position in the regenerated worm that they did in the parent animal; and Ivanov has shown in *Lumbriculus*, that the histological development of the seven anterior 'head' segments follows a different course from that of the rest. Child has concluded from his studies on Planarians 'that the head which appears in the reconstitution of a piece is not physiologically part of the piece and is not formed by the piece, but develops, so to speak, in spite of it.' (2.p. 113.) This is a hard saying, but we may bear it, if the facts I have given as to the process of head-formation in Polychaets are borne in mind. They show that the metabolic and morphological changes evoked by section are not those characteristic of the neck region in which they arise. They pursue a course of their own analogous to that followed by the normal pre-oral or apical lobe, and produce a complex structure in which the brain appears as a new development; whilst further back the new differentiator leads to the independent new formation of the mesoderm of the thorax and abdomen. The whole process is strikingly reminiscent of the two similar lines of metabolic activity in the embryo of the worm or of the frog, and constitutes confirmatory evidence of the existence of a co-ordinated system of gradients.

A peculiar corollary arises out of a consideration of animals that may possibly present two apical regions at opposite ends of the major axis. I venture to suggest that Lamellibranchs might prove unusually interesting if examined from this point of view. It is also possible that Cestodes would give interesting results, especially in the case of those irregular growths known as *Sparganum*. One of the virtues of this hypothesis is that it makes old things new and suggests new problems for investigation. Above all, it has led to the power to predict and control the results of experiment on two groups of animals, the Oligochaetes and the Planarians.

Summing up the evidence adduced in support of the 'gradient hypothesis,' I am inclined to regard its value as indicative rather than demonstrative of that hypothesis, as its suggestiveness exceeds, in my opinion, its conclusiveness. Above all, this hypothesis suggests, and suggests perhaps for the first time, a method by which the problems of development can be linked up with those of genetics.

Periodicity as a Fundamental Mode of Action.

The animal according to this view is a system of periodic change. The system, as a whole, tends to slow down, but each part of it, each organ, works in shifts which permit every working group its period of rest. While resting, their capacity for output is increased, and on working again their rate of metabolism rises, falling again as the function progresses. Cycles of activity and morphological cycles are essentially age cycles. In the

higher animals, the organism as a whole becomes, under conditions of our present imperfect control, irrevocably older, and each cycle of rest brings with it less rise in metabolic rate. In the lower animals and in hibernating members of the higher forms, extensive rejuvenescence takes place. The senile effect is indefinitely postponed. Physiological isolation of a part occurs from various causes—increased growth and relatively decreased subordination to dominance, position off the line or beyond the main force of the gradient. Such isolated regions re-acquire the higher rate of metabolic change, and establish a new gradient system or a renewed system based in either case on local differences in rate of stimulus. Such physiologically isolated pieces we call germ-cells, buds or spores, but there appears to be complete gradation between the rhythm or cycle of rest and activity in the functional units of an organ, and the periodic ripening, discharge and activation of ova or the periodic production of medusae and of resting stages of Polyzoa or Sponges. To use Professor James Johnstone's phrase, the tendency of the universe to run down, or of entropy to increase, is opposed by phases in the cycles of life. The alternation of the physiologically younger state with the more highly differentiated older state is fundamental.

Periodicity in Organic Function.

Intimately connected with the idea of the organism as a synthesis of co-ordinated control is the principle of periodicity in the functioning of organs. This is a development of an old idea and is widely recognised by physiologists and pathologists. It may be expressed in the phrase that at any time the organism or any part of it, is a function of its own cyclical period, or, as I have just expressed it, an animal works its organs in shifts. What the shift-unit may be for each organ we do not know; we do know that, for the higher animals, more tissue exists than is needed for well-being under average circumstances, and that when a time of special stress ensues the emergency is met, not so much by increasing the pressure on the working shift, as by calling up the reserves and throwing them into the general action.

The evidence for 'partial activity,' as the pathologists call this economic exercise of function, is partly direct, by tests indicative of activity or repose, and partly by the results of observation on the removal of organs or parts of organs. The glomeruli of the mammalian (rabbit) kidney have, by suitable means, been made to show their fields of activity at a given moment, and the result shows patches of active glomeruli alternating with inactive ones. Again, removal of a large portion of the liver is not necessarily fatal to man, nor is it essential that both kidneys should be present. Removal of one of the kidneys and a study of the after-effects confirms the conclusion that one kidney can do the work of both, and that a much smaller liver than is normally present can sustain the body in health. Similar conclusions apply to other tissues, and there is great need for the extension of research on these lines to the partial activity of animals.

Two considerations of great practical importance for our present study of control as a principle of organisation arise out of an analysis of this view of cyclical functioning of parts of an organ. The first is that the resting shift is receiving less blood and is more resistant to disease than when it is working. It is in a state of less active metabolism, and while recovering

from the effects of its spell of work has become temporarily physiologically younger. The second consideration is that the age of the animal counts as an important factor in the final result. The removal of one kidney from an adult throws the entire excretory function on to the other, and thereby increases general susceptibility to disease or breakdown where previously only local susceptibility occurred. But in the case of a child the result is quite different. In this case, the remaining kidney develops its reserves, forms additional tubules and glomeruli, and ultimately attains a volume equal to that of the two original organs. It is thereby enabled to continue its action on the lines of partial activity, and to afford each of its functional units their periodic phases of activity and repose. I trust that I may be pardoned for taking a leaf or two out of the book of pathology for the purpose of illustrating, not only the principle of control, but also the great benefits to biological sciences that will accrue by a fuller mutual recognition of the advances made by pathologists and zoologists.

Nervous Control.

Another outstanding example of the working of control in the organism is afforded by the progress of neurology, in which your own earlier nominated President and the President of Section I for this meeting have taken such a prominent part. The brain of man is now regarded as a hierarchy developed for control. The existence of its members, their activity and degree of suppression or of dominance and subordination, as well as their intricate relations to the body and its environment, are matters of interest to all of us, and their consideration may fitly introduce the larger aspects of control with which I shall presently deal. The brain is, in fact, the highest expression of the activity of that co-ordinated system of metabolic gradients which integrate the physical basis of life into individual being. If I may venture for a moment into these deep waters, it is rather to illustrate the existence of control than to expound that relation of the nerves to the gradient hypothesis upon which Professor Child has recently issued a special memoir (11).

The well-known experiments performed on the arm of Dr. Head, and since repeated by others, revealed more fully than before the normally suppressed nature of the thalamic complex. The acute but uncritical sensations that he experienced during the return of sensibility—the protopathic form of sensation—represent in all probability an early stage in the sensations of vertebrates, and one connected with the optic thalami as that primary group of centres in the stem to which all sensory impulses converge. The subsequent return of normal epicritic sensibility marked the relative suppression of the thalamus by the higher cortical centres in the neopallium. The experiment caused a release of suppressed function. The lower order of the hierarchy was, for a time, allowed to exercise something of that disorderly, acute, and uncritical sensibility which has been in part incorporated into, but largely suppressed by, the more critical and dominant centres of the cortex. In some such way, the control that civilisation exerts upon society is thrown off by its retrograde units who indulge in disorderly, acute, and uncritical actions until forcibly restrained from so doing by the higher powers.

In connection with the subject of nervous control and the development of social life, I should like to draw attention to the social insects whose

activities have lately been reviewed by one of the most scholarly entomologists of the day, Professor Wheeler. In his new book on the subject (12), Wheeler mentions, without, however, stressing the significance of the subject, that the advance from the solitary condition (that is, a pair of wasps, bees, or beetles making separate nests) to the social state is associated with two factors. First, the mother does not, as do the solitary forms, die after oviposition, but in virtue of special food she is able to survive the birth of her offspring; and secondly, and more significantly, she touches them and they touch her in the act of feeding. It is this touch of nature that seems to make real kinship between mother and offspring, and that provides the starting-point for the development of that highly specialised group of societies into which insects alone have the entrée. It would be of the greatest interest to make a comparative study of the nervous system (particularly of the brain) of those bees, wasps, and beetles that exhibit the first touch of social genius. In its more advanced forms, control exercises the most diverse influence upon the whole economy of the insect society that practises it, one of the most curious being the control of the digestion of a specialised article of diet (wood pulp) by the Flagellates that live symbiotically in Termites. Termites have apparently discovered and exploited the cytolytic ferment that these Flagellates exert, and by a process of rectal feeding of their own young they ensure that each larva is provided with the necessary digestive ferment.

The Control of Environment.

The organism, however, does not exist except as relatedness. We are too apt to abstract it as a concept from its inner environment and from its setting in the outer environment which are really part of its being. The acid test of this proposition is the mature but unfertilised egg. As I have pointed out, this microcosm is a system of readiness for complex and energetic development, but is without contact with the outer environment. It is a closed system. It is physically as well as physiologically alone in the world. It hovers between life and death. As a (physiologically) highly differentiated system, formed late in physiological history of the individual, it is what Child calls a senile cell. Tested by the susceptibility method, by respiratory exchange and by heat production, the mature egg of most animals is inactive, and, in contrast to the rate of change it will exhibit if fertilised, may be said to be inert. If now this closed static system is put in relation to the outer world, the response is immediate. Drastic changes convert the static into a highly dynamic system. A dynamic relation between the egg and its environment is then a necessary condition for the initiation of development, and the 'environment' of later stages is but an elaboration of the 'relatedness' opened up by fertilisation.

The internal or humoral environment, elaborated by the organism and controlled by its hormones forms one of the 'normals' of the higher animals. This chemical correlation is associated with the acquisition of external normals largely but less surely independent of changes in the outer world. The place in nature, the environment that has become, as it were, part of the organism—constancy of temperature, steadiness of balance in the face of altering conditions—is gained *pari passu* with the establishment of normals of internal environment. Regu-

lation of its place in nature, 'choice' of environment (including the presence of other organisms as well as the conditions of life in the restricted sense), adherence to a selected field of outer impulses, constitute an essential feature in that relatedness which constitutes individuality. 'I am part of all that I have met.'

A few illustrations taken from recent ecological work may not be unwelcome. Mr. Eliot Howard (13) has concluded that spring migrants to England each after their kind select and guard a territory on their arrival. The distinctive song of the cock announces this achievement to the later flight of silent passing hens, and mating is but a prelude to a continuous policing of the stretch of hedge, area of moor, or piece of covert whose boundaries, to us invisible, are clear to them. The intrusion of another cock of the same species is hotly resented, and fierce engagements, extended it may be, to the cocks and hens of other species, are continued, up to the boundary and then suddenly cease. The bird and its environment—the territory—have become one activity, and it is restless till it has established itself in its niche. Just so, to take a more familiar example, each member of a Council or Parliament at each sitting has to regain his orientation both to place and to person before he can be at rest and at his best. As J. S. Haldane has put the matter, 'regulation of the external environment is only the outward extension of regulation of the internal environment . . . An organism and its environment are one' (14, pp. 99).

If we now apply the principle of physiological isolation to the organism as influenced by, and influencing, its external environment, many well-known facts of zoological distribution become intelligible. Isolation arises from many different causes—by isolation by growing size, by decrease in conductivity in the path of transmission from the dominant region, by decrease in dominance itself, or to a change in the conditions of life—and no general statement can be made that will cover all cases. Bearing in mind, however, that life under dominance tends to exhaustion, whereas isolation leads to the renewal of activity at a lower level of complexity, we should be prepared to find that organisms change their environment with change in their physiological conditions, and that historically there would be 'backwaters' of those stocks that represent ancient stages of more progressive races; and we should further expect that these 'islands' would possess a higher metabolic rate than the more differentiated and highly integrated races. To them rather than the dominant races we should expect the future to belong. From others, like them externally perhaps, we should expect neither progress nor repression, but a balance that, indefinitely perhaps, postpones the evil day.

These relations we do find. The indefinite persistence of Lingula and Nautilus on the mud flats and depths of the Fijis in the Far Eastern seas, of Pleurotomaria in the Far East and West, the general isolation of 'living fossils,' is on this view to be regarded as a balanced senescence. Even in the most progressive regions of the world there are islands or backwaters where such arrested balance maintains a precarious existence. Proteus and other primitive forms survive only in the Balkan peninsula. Primitive societies of mankind or primitive customs likewise survive in those isolated communities of a progressive race. Modern industrialism creates such islands where the raw material or the working conditions demand isolation

from the larger towns, and in this way acts favourably to the biological future of the island communities.

The question as to what determines or inhibits the 'progressive' development of an isolated animal or human group, provided as it is with an actual or potentially higher metabolic rate than that of its more dominated portion, is a question of the greatest interest. In so far as isolation leads to greater 'individuation,' we may look to the isolated as the source of fresh individuality and power to wield dominance, to be paid for in time, however, with the inevitable price of diminished progress. A careful survey of closely allied species in certain groups of animals (Fishes, Echinoderms) has shown that the nearest allies of a given species occupy widely separated areas. Thus, the common European Starfish has its nearest ally on the opposite coast of Canada and America, and the sea-urchin, *Echinus esculentus*, has its nearest ally in blood far removed in space. Canada and Scotland might serve as a typical example. Just as conditions of existence form one of the factors governing isolation, so the readiness to make a change of function in 'adaptation' to a consensus of favourable conditions may determine the advance. The heightened metabolic activity of the isolated ones may then profit by the new environment which they incorporate into their new individuality.

Professor Elliot Smith has emphasised this view of the origin of civilisation. If, as we all hoped, he had addressed you, I venture to think that in his mind, if not expressed in his words, would have been that thought 'the readiness is all.' Many tides in the affairs of men may have washed the islands of the strong isolated groups before their concurrent benefit was grasped and developed. Egypt and Western Asia was not the only area where the earth would have seen the birth of civilisation, but elsewhere, perhaps, the readiness was lacking even if the physiological impetus was stored in the biological history of the people. So it may have been with the history of animals and so it may be in the future. 'In the reproof of chance lies the true proof of men.' Yet chance has other gifts than harsh reproof.

Zoology as a Factor in Civilisation.

When we consider the principles of periodicity of regulation in form and function, and of that characterisation of successive generations which constitutes genetics, we cannot help concluding that, so far as they are fruitful in stimulating inquiry and true to the best of our limited critical knowledge, they should serve to a much larger extent than is now the case in human thought and endeavour. I am not now referring to such knowledge as having merely a pragmatic sanction. Usefulness is not the justification for the study of biology. Wisdom is justified of all her children. It is because we are the outcome of the biological process that a science of life will provide men with a truer understanding. Biology in the Greek sense will be founded on the biology of science.

Such recognition of its basal position has not yet been obtained by biology. The progress of industrialism, the application of physics and chemistry to national needs and national entertainment have won, for physical science, an appreciation and a belief which, even if unreasoned by the majority, has, I believe none the less, that sanction which gives weight

to convinced public opinion. Nor are there wanting those who look to the development of physical science, alone or in the main, as the lodestar of modern civilisation. They may point out that even in those industries, such as animal and plant husbandry, that are most biological in character, the subject-matter so far as it is biological is dealt with in an empirical way, untouched by modern biological principles. The selection of new varieties, and the whole process of animal breeding in the world of racing and agriculture, is a cult now as always entirely cut off by science, but possessing the vigour and initiative that physiological isolation confers. The real ecologists are those—the fishermen, hunters, trappers—whose wonderful empirical knowledge and nomenclature contains more than can be reduced to the dimensions of that bed of Procrustes, our formal science of animal life. The advocate of physical dominance might even go further, and suggest that just in as far as modern civilisation had spread, to that extent had biological interests receded; that the world of biological evolution, the natural faunas and floras of the unmastered spaces, were bound to succumb to the dominance of civilisation; and that unless the biologists take heed, their very material for study will be reduced from the irreplaceable and almost infinitely rich variety of the wild, to the monotony of the house fly and house sparrow, and biology will become a mere *ancilla* to medicine and gardening.

The *advocatus diaboli* has put forth his pleadings. How is the counsel for the defence to state his side? He can point to the need for taking the long view. He is convinced that man as man, and not as a temporary phase in an unstable scheme of things, is a biological creation; that as part of his invincible faith in evolution, the study of the products of evolution will throw light on man's body, mind, and destiny. But just as dominance and freedom from dominance are creative but correlative, so the over-mastery of a dominant scheme, the tyranny of organisation may lead, after a period of effective differentiation to a slowing down of the natural spirit. The reaction, the return to individualism, the principle of isolation as I have called it, is the natural result. The problems of social philosophy, even the problems of government and civil life—biology in the Greek sense—are illuminated by the principles of zoology, and if the flame is at present flickering, weak, with little pressure behind it, there are those in this and other countries who have faith in its future brightness. This light shining strongly in the west, is a rising star. The astronomer will be satisfied to take his pleasure in its understanding, but it will also pilot the way for those who in many countries have long wanted a lamp to their feet and a light to their path.

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SECTION E.—GEOGRAPHY.

INTER-RACIAL PROBLEMS AND WHITE COLONIZATION IN THE TROPICS.

ADDRESS BY

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CONTENTS.

I. The Modern Increase in Population.

The problem of the present century, according to many observers, is the problem of the colour line. We are warned from one side of the danger to civilization of the rising tide of colour; and from the other of the peril to humanity from the rising tide of colour prejudice. The difficulties of the racial problems have been intensified by the unprecedented increase in the world's population. According to the estimates in 1696 of Gregory King, a pioneer in political statistics, the utmost population which England could support would be 22 million and that number would not be reached

until the year 3500 or 3600—'in case the world should last so long.' In the year 1900, according to his expectations, the population would have amounted to only 7,350,000. These egregious miscalculations are a warning of the uncertainty of statistical forecasts as to population and an illustration of its surprisingly rapid increase in the modern world owing to the application of science to commerce, industry, and public health. This accelerated increase is mainly due to the European race, but it has been most rapid in Africa and Asia in consequence of the reduction by European administration of internal war, plague, pestilence, and famine. From 1906 to 1910, to quote the latter half of the last normal decade, the population of the world grew at the rate of doubling in sixty years. If this rate were to be maintained the 6,600 millions of people, which it has been calculated is the most that the world can feed, would be in existence in 120 years; and even if the food supply were indefinitely multiplied by the precipitation of the nitrogen of the atmosphere as a constant rain of manna, standing room on the earth, exclusive of the remoter Arctic and Antarctic lands, would be all filled when the population numbered 700 billion (*i.e.* million million) in the year 3000.

The rapid increase in the population of the world during the last half-century has had disturbing political influences. Thus many parts of India have apparently almost the maximum population possible under existing economic conditions, and the slow present increase is gained painfully to the accompaniment of irrepressible discontent. Countries which once had extensive empty lands have begun to close their ports to aliens, in obedience to the principle that each land must consume its own surplus population. The United States, the 'melting-pot' where the mixed races of the Old World were being fused into a new type, has adopted measures based on the growing belief, in the words of Lothrop Stoddard, that 'the book of race migrations must be closed for ever.' The halt at Ellis Island has already warned eastern and southern Europe that America is no longer an open asylum for refugees. The three great natural outlets from Asia have been closed by the prohibition of immigration thence into western America, by the 'White Australia' policy, and by the refusal of eastern and southern Africa to accept further Asiatic contributions to their needed enlarged supply of labour. The struggle for expansion, which was the ultimate motive of the World War of 1914-18, will inevitably be still more bitter and terrible if it become a struggle for existence between the White and Coloured races.

The effort to foresee the future progress of the world raises two contrasting visions. The increase in the wealth and prosperity of all the continents by the influence of the European race may be continued, either by colonization, as in America and Australia, or by administration, as in Asia and Africa. Asia, by improved industrial methods, and Africa, relieved from the slave trade, may continue to advance in co-operation with the European race instead of under its government; and European control may be voluntarily withdrawn as sympathetic alliance replaces the older systems of servitude. If those developments take place the twentieth century will be indeed a golden age.

The alternative picture is darker. Europe, during the past fifty years, like Portugal in the sixteenth century, may have taken on tasks beyond its power. The drain on the manhood of Portugal by its vast colonial

empire reduced the home population by half, the land went out of cultivation, the country was stricken by famine, and Negroes were introduced to till the derelict farms and then absorbed into the nation. The dilution of the Portuguese by Negro blood is often regarded as one of the main causes in the fall of Portugal from its former political, scientific and intellectual pre-eminence. Has Europe been led into the same enterprising but disastrous error? Has it undertaken the administration of larger areas than it has the *personnel* to maintain? Will, for example, the African troops in France have a similarly demoralizing effect as the Negroes in Portugal and the slaves carried into Italy during the decline of the Roman Empire?

II. The Races of Mankind.

Consideration of inter-racial problems requires a classification of the races of mankind. The most popular classification is that into four races based on colour—the white or European, the yellow or Mongolian, the brown or non-Mongolian Asiatic, and the 'black' or Negro. These colour names, however, are only valid if used in a conventional sense, which is often inaccurate.

The character of the hair forms a more reliable basis and it divides mankind into three primary races—the Caucasian, Mongolian, and Negro. The Caucasian has abundant wavy hair; the Mongolian long, lank, black hair; and the Negro short woolly hair. This classification is only politically suitable if the Caucasians be subdivided into two sub-races, the fair-complexioned people of northern Europe, who were named by Huxley the Xanthochroii, and the Dark Caucasians or brown people, the Melanochroii of Huxley, who include the south Europeans, and some still darker people in Asia and Africa.

The numbers of the white, yellow, brown and black divisions of mankind, according to the returns for the last available year before the war, were—white or European race 520 million; Mongolian 620 million; brown 370 million; Negro 190 million—total 1,700 million. The coloured races are in the majority of more than 2 to 1. The advantages conferred on the Whites by their more efficient organization, better equipment, and command of transport and machinery should enable them to hold their own in any direct conflict, in spite of their inferior numbers. The danger to the white race comes from their dependence on trade with Asia and Africa which would be jeopardised by the restoration of the political conditions that held before those continents fell under European influence. The maintenance of European dominion lays a heavy burden on the white race, as it is responsible for the government of eight-ninths of the habitable land of the globe. One-third of the inhabitants of the world rule eight-ninths of it; the remaining two-thirds of the people control only one-ninth of the land.

This condition is modern. A thousand years ago the Whites held only part of Europe, for Spain was then ruled by the Moors and south-eastern Europe by Asiatics. Four centuries ago the white race had secured nearly all Europe; but the coloured races still ruled the rest of the world. The formula of Asia for the Asiatics and Africa for the Africans was then accepted, as well as America for the Red Indians. Even at the beginning of the last century only the coastal belts of North America

and a few small settlements in Africa and Asia were occupied by the Whites. During the last century, and especially since the development of railway and steam navigation after 1840, the whole of America, all Africa except Abyssinia and Liberia, all Australia, and all Asia, with the exception of China, Japan, and Siam, have fallen under the control of European people. Since 1900 European influence has, however, suffered extensive reductions in Asia and Africa, which have advertised the relative decrease in the number of white people. During the past half-century the unprecedented increase in the white race has been exceeded by that of the coloured people.. Increased disparity in numbers means, in a democratic age, an inevitable transfer of power; while the former prestige of the white man has been undermined by his own beneficent rule. Alike in war and peace the personal authority which the white man held in 1900 has undergone a momentous decline.

III. Geographical Principles.

Whether that movement is a temporary set-back or a permanent change in inter-racial relations is a problem on which Geography should afford the most reliable available guidance. If we accept the scope of Geography as the study of the earth with especial relation to man, its primary duty is to collate the results of other sciences which throw light on the major problems of human development. It should learn from physiology the effects of climate, altitude, and tropical sunshine on the different races of mankind; from biology what diseases are due to parasites and how infection may be prevented; it should find from agriculture the most profitable local crops and how to improve the food supply; it should discover from geology the nature and distribution of soils and the available supplies of minerals and mineral fuels; and it should seek from the ethnologist guidance as to the characteristics of the races who are competing in the struggle for existence. The geographer provided with this knowledge should endeavour to weigh evenly, free from race prejudice and political bias, and undisturbed by the fears of vested interests, the factors which control the distribution of mankind.

The ruling geographical principles as to the distribution of the three primary races may be summarized as follows: 1. The population must be scanty in the colder regions of the world owing to their long severe winter, and also in the dry deserts, except in those relatively small areas that can be watered by irrigation. 2. The tropical regions have hitherto been the home of the coloured races, while the white nations have been mainly restricted to the temperate zone. 3. When different races live side by side, the more primitive race, unless conditions be imposed on it fatal to its spirit, will outlive the other wherever the struggle for existence is keen.

From these principles two main inferences can be drawn. First, the frigid zones, the chief deserts, and the tropical plateaus above 12,000 ft. or so above sea level will always have a sparse population, and will long be left except for occasional commercial, mining, and industrial centres, to the most primitive tribes who have access to them, such as the Eskimo in North America, the Lapps in Europe, and various hardy, easily contented Mongols in Central Asia. Second, white colonists have no chance of per-

manently occupying land near the overcrowded parts of Asia or accessible to the fast multiplying Negroes of Africa. White merchants may find in these regions profitable trading centres and may for a time rule and administer them; but when white enterprise has subdued the land, built railways and utilized the rivers, the coloured man will oust the white from all but the few posts that require experts.

IV. Inter-racial Relations.

The relations of the white and coloured races living in the same land may be settled on any one of four lines—amalgamation by miscegenation; co-residence without fusion, and with complete social separation; the disfranchisement of the coloured population as State wards; or the segregation of the different races in separate countries or communities.

1. (*a*) *Racial Fusion.*—Amalgamation by complete racial fusion is often recommended as being either inevitable or desirable, or both. That plan is recommended by the improvements in stock and plants wrought by judicious interbreeding, and mankind may be expected to benefit by the same process. The great modern nations are of mixed origin, and their efficiency is doubtless due to the varied capacities inherited from their miscellaneous ancestors. Accordingly many authorities, such as Lord Olivier, anticipate the settlement of serious difficulties and the betterment of the human race by inter-racial fusion. Lord Olivier claims that mixed races are superior to those of simpler constitution. 'So far, then,' he says, 'as there survives in a mixed race the racial body of each of its parents, so far it is a superior human being, or rather, I would say, potentially a more competent vehicle of humanity' ('White Capital and Coloured Labour,' 1906, p. 22). H. G. Wells regards inter-racial prejudices as one of the worst of existing influences. 'I am convinced myself that there is no more evil thing in this present world than Race Prejudice; none at all, I write deliberately—it is the worst single thing in life now. It justifies and holds together more baseness, cruelty and abomination than any other sort of error in the world.' Its strength he considers renders it impossible for two races to live separately and in amity side by side. 'Racial differences,' he declared in an earlier statement,' seem to me always to exasperate intercourse unless people have been elaborately trained to ignore them. Uneducated men are as bad as cattle in persecuting all that is different among themselves. The most miserable and disorderly countries of the world are the countries where two races, two inadequate cultures, keep a jarring, continuous separation' ('The Future in America,' 1906, p. 273).

The benefits of interbreeding, according to many authorities, are limited to parentage nearly akin, though in such cases the advantages are well marked, as exemplified in Canada. Intermarriage in mankind, it is urged, should be restricted to nearly related people. Herbert Spencer, in a famous letter that was not published until after his death, declared that the interbreeding of widely different types produces weak inferior offspring, with 'a chaotic constitution.' This view has been supported by modern students of Eugenics. Major Leonard Darwin, in a letter to the members of the recent Imperial Conference (1923), urged that 'theoretical reasons can be adduced for believing that interbreeding between widely divergent races may result in the production of types inferior to both parent stocks;

and that this would be the result of miscegenation is at all events a common belief.' Dr. J. A. Mjoen—who, according to Major Darwin, has made a long study of these questions and is 'an authority well worth considering'—after detailed study of the Mongolian-Caucasian hybrids in Norway, reports that the children of these Lapp-Norwegian unions are inferior physically and mentally. He concludes from his investigations that 'crossings between widely different races can lower the physical and mental level.' He urges 'Until we have more definite knowledge in the effects of race-crossings it will certainly be best to avoid crossings between widely different races' ('Eugenics Review,' 1922, vol. xiv, p. 39).

Professor Lundborg, of the Upsala Institution for the Study of Race Biology, has adopted the same conclusion. He deplores 'hasty race-mixture between nations who, from a race-biological point of view, stand too far apart.' He declares that 'a mixture between nations who, from a race-biological point of view, stand high and others containing lower race-elements, such as gipsies, Galicians, certain Russian tribes, etc., is certainly to be condemned.' Lord Bryce has twice asserted the same conclusion. According to this view mongrels (the offspring of different varieties) should be better than at least one of the parents, while hybrids (the offspring of different species or primary divisions of mankind) are necessarily inferior to both parents.

This doctrine cannot be regarded as established, but the strong intellectual aversion to such unions among the Teutonic people will doubtless prevent the adoption of race amalgamation between the Negro and the Whites in North America or of northern Europe. Opinion against this policy is hardening in the one country, the United States, where it might be expected to find most support. There, intermarriage between Whites and Negroes is illegal in most of the States, and opinion is against it on both sides, except in so far as it is welcomed by one section of Negroes who would tolerate it to overthrow the social restrictions imposed upon them.

1 (*b*) *Racial Fusion in South America.*—The system of Race Fusion has been followed in tropical South America, which is occupied mainly by a hybrid people. The intermarriage of Spaniards and Portuguese with Indians and Negroes has proceeded to such an extent that only a small uncertain proportion of the inhabitants are of pure European descent. The population of tropical South America is a mixed race with the exception of small clans in some of the cities of Ecuador and northern Peru. In most of South America there is said to be no more prejudice against the mixture of races in marriage than there is in Europe against that between different social classes. The limitation of marriage in South America is by class not by colour.

'Everything' in South America, said Bryce ('South America,' 1912, p. 565), 'points to a continuance of the process of race mixture.' 'Miscegenation,' says Garcia Calderon ('Latin America,' 1913, p. 356), 'is universal in South America between Iberian, Indian and African.' 'A single half-caste race,' he says (*ibid*, p. 338), 'with here the Negro and there the Indian predominant over the conquering Spaniard, obtains from the Atlantic to the Pacific' and from Mexico to Patagonia. The predominance of the white race may be maintained in the southern parts, but most of South America seems destined to be the home of a hybrid Indo-Negro-

Iberian race. South America illustrates the results of miscegenation on a continental scale.

2 (*a*) *Co-resident Distinctness.*—The second available inter-racial development is by co-residence with the maintenance of racial distinctness. The greatest experiment with this policy is in progress in the United States. It is recommended there by leaders of both White and Negro opinion as the only solution of the inter-racial difficulties. Its most effective champion was the late Booker Washington, who is generally regarded as the greatest Negro whom America has yet produced. This policy aims at the association of the two races in work, but their complete social separation. According to Booker Washington's famous analogy the two races should be separated in life as completely as the fingers, but as fully united in work as the hand. This idea attracted support from various sides, as it offered a practical basis for development, and involved the renunciation by the Negro, at least for a time, of his claims for political and civil equality. This policy is dependent on the better education of the Negro. Booker Washington, amongst his other titles to fame, was a pioneer in agricultural education; and the success of his institution at Tuskegee has undoubtedly done much to raise the American Negroes. He has, however, been violently condemned by many of his compatriots, owing to his asserted surrender of their claims. According to these critics the advance of this policy has been attended by the lowering of the civil and political status of the Negro, and the intensification of inter-racial feelings by raising the jealousy of the southern Whites at his improved educational and financial position.

The possibility of long continued associated distinctness by two intermingled races is contradicted, according to some authorities, by historic experience. Lord Bryce states that 'whoever examines the records of the past will find that the continued juxtaposition of two races has always been followed either by the disappearance of the weaker or by the intermixture of the two' ('The American Commonwealth,' 1911, vol. ii, p. 532). Professor Kelly Miller, of the Howard University, Washington, expresses his conviction 'that two races cannot live indefinitely side by side, under the same general régime, without ultimately fusing.' A. B. Hart, Professor of History at Harvard University, is more hopeful, and he cites the long continued co-existence of Hindu and Muslim in India, of Boers and Kaffirs in South Africa, and of English and Indians in North America; but these cases give no more encouragement to the prospects of Negro-Caucasian association in America than do those of the Jews and Parsees.

2 (*b*) *The Position in the United States.*—Whether this policy is possible or not the testimony is overwhelming that the attempt to adopt it in the States has been attended by increasing tension and race bitterness, despite all the influences in its favour.

Under the auspices of a Commission for Inter-racial Co-operation 800 county inter-racial committees have been established. The two races have been uniting more often in educational and social work, both by informal association of neighbours, and by such organizations as the University Race Commission, the Southern Sociological Congress, the Rosenwald and Jeanes Foundations for the building of Negro Schools, the Phelps-Stokes Fund, the General Education Board and its Rockefeller Endowment, and by the munificent gifts of northern benefactors to

Hampton and Tuskegee. Moreover, the State Courts, by their decisions as to Pullman cars, have lessened the rigour of the regulations which separated white from coloured passengers on the railways; and the Supreme Court of the United States, once regarded as unsympathetic to the Negro, has dismissed as unconstitutional some of the State laws that have been used to disfranchise him. Many circumstances favour the growth of more friendly feelings between the two races.

Nevertheless, the general testimony of writers on the United States during the past twenty years is that the position has been, and is, going steadily from bad to worse. 'The two races,' says Professor Hart (1910), 'are drifting away from each other and race relations are not improving.' A. H. Stone remarked in 1908 the increasing growth of race feeling among the Negroes. Lord Olivier in 1906 predicted that the policy which was and has been followed 'will doubtless in time bring about civil war.' William Archer, comparing the conditions in 1910 with those at the Atlanta Conference when Booker Washington put forward his co-residence policy, declares 'that the feeling between the races is worse.' W. P. Livingstone, a writer with West Indian experience, wrote in 1911 ('The Race Conflict,' pp. 13, 31) that the negro question 'remains, what it has been for a century, the darkest and most menacing cloud on the horizon of national life,' and that 'the situation is described as being worse to-day than at any time since 1865.'

'Any competent observer,' said Maurice Evans in 1915, 'must see in the South, as in South Africa, a gathering storm, which means ultimately not only industrial war, but industrial war *plus* racial conflict.'

The World War for a time appeared to improve the Negro position, owing to the labour shortage in the United States due to the stoppage of immigration from Europe and the urgent demand of the belligerents for munitions. But after peace the irritation of the Negroes at what they regarded as the systematic belittling of their war services and the friction due to increased contact in the cities led to serious race fights during 1919 at Washington, Chicago, Elaine, St. Louis, and Knoxville. These riots, with the determined defence offered by the Negroes, justify the insight of Livingstone's warning—'So gigantic does the problem appear, so difficult of peaceful solution, that the nation is helpless in face of it. It has become so subtly connected and interwoven with all the organic texture of the national existence that the people, as a whole, are afraid to make it a living question, not knowing what might be the result. There is an uneasy consciousness of the truth of the Southern warning, that the forces of the revolution, unspent and terrible, are ready at any moment to break out under sufficient provocation.'

3 (*a*) *Racial Segregation in the United States.*—So alarming does the position appear that three drastic solutions have been proposed based on the separation of the Negro community by political disfranchisement, exile, or segregation.

The first is the complete disfranchisement of the whole coloured population, including all with any appreciable proportion of Negro blood, and its tutelage under a special Board of guardians. The Negroes would have separate police and law courts, and separate schools in which the training would be mainly industrial. They would be wards of the State, and would elect representatives to their Board of protectors,

but would have no votes for the Federal or State Parliaments. A plan for treating permanently a seventh of the population as irresponsible helots would appear utterly inconsistent with the American Constitution, and impossible in modern conditions under any democratic constitution; and the Negroes, and especially the 'Near Whites' who are predominantly white by blood, would regard the status proposed for them as an intolerable degradation.

A second and still more drastic suggestion is the compulsory emigration of the whole Negro population to some such places as Hayti and Liberia. This solution was advocated by the distinguished American palæontologist, E. D. Cope, and it was favoured by Abraham Lincoln until he was persuaded that the whole of the North Atlantic shipping could not remove a sufficient number to keep up with the normal increase in the Negro population. The scheme has been often rejected as impossible on the grounds that the American Negroes are too numerous for transhipment, and that there is now no available room for them either in the West Indies or Africa. These difficulties would not be insuperable if the United States were determined to overcome them, and the Negroes were willing to go; for any such migration would obviously have to be spread through a considerable period and neither the cost nor lack of room for the emigrants would be beyond the power of so wealthy and resourceful a nation. But the project is not worth discussion here, as the political difficulties place it out of court.

An alternative segregation policy is that of collecting all the Negroes into one territory or State within the United States. That scheme might have been practicable in 1865 at the close of the Civil War; but as the areas suitable for Negro settlement which were then available have been occupied, this proposal appears as much a counsel of despair as that of transplantation to Africa and Hayti.

The only scheme of segregation within the sphere of practical politics is that for the assembly of the bulk of the Negroes in numerous scattered agricultural settlements where they would be withdrawn from close daily contact with the Whites, but would co-operate with the rest of their fellow-citizens in productive work. This agricultural ghetto policy would probably lessen inter-racial friction; but it would leave the Whites and Blacks in contact on so many surfaces that it might still lead to a slow process of fusion, and would not secure the permanent separation of the two races. The champion of this policy, Maurice Evans, indeed admits that it offers no final solution of the race problem in the United States. 'There is,' he says, 'no final solution possible, and the Negro will remain a problem for generations to come.'

3 (*b*) *The Probable Developments in the United States*.—If, therefore, of the three constructive policies absorption is rejected as it would make the United States a nation of octoroons, permanent distinct co-citizenship be impossible, and segregation be impracticable, what development is possible? No single measure that could be imposed on the country by the Legislature appears to be available, but some solution may be reached by a process of drift. It is for the geographer to search for the factors that are likely to guide this drift.

One most significant movement in the southern States is for much of the agricultural work to pass into the hands of immigrants from southern Europe, while the Negroes, through that restlessness which is the weakest

element in their character, tend to settle in the towns. Stone, a representative southerner, remarks that planters must seek more reliable labour than that of the Negro, who has already been replaced in tobacco cultivation in Kentucky. Booker Washington repeatedly called attention to the seriousness of the danger that the Negro would be driven from the skilled occupations. The recent agreement between Italy and Mexico for the settlement of 500,000 Italians in Mexico would provide an additional source for Italian inflow into the southern States. The feeling against inter-racial marriage is not so strong among the people of southern Europe as it is with the Teutons; hence extensive south-European immigration into the cotton districts may lead to their future occupation by a hybrid race similar to that of tropical South America. This process would render impossible the continued refusal of political and municipal rights to any citizen who has a trace of Negro blood. The coloured people would regain the suffrage, and the political development of the southern States on normal American lines would be impossible. If the Whites in the southern States be divided between Republicans and Democrats, the Negro vote would hold the balance of power; and owing to the considerable over-representation of the southern States in proportion to population, American politics might be determined by the Negro vote. Such a situation would be intolerable to the northern and western States. Hence, to avoid it, they might agree to the south-eastern States being formed into a group with a special measure of home rule in some departments of Federal jurisdiction.

This solution may take a century or more to develop; but the geographical considerations indicate it as the most probable issue from the Negro strength in the south-eastern States.

3 (*c*) *Segregation in South Africa.*—The system of inter-racial development by the segregation of the different elements in the population, though apparently impracticable in America, is one of the main issues in current South African politics.[1]

In Africa, the racial problem, as far as concerns the white and coloured races, is simple in most parts of the continent owing to the overwhelming majority of the coloured population. In Algeria and Tunis there has been an extensive settlement of south-Europeans, with whom the native Berbers are racially allied. Most of Africa is the home of Negroes, whose numbers are increasing faster than any other population in the world. European officials superintend most of the continent, but they and the European traders are few in number and are usually temporary sojourners. In a few localities, such as the Highlands of Kenya and of Nyasaland, the European colonies may be permanent; but even in these localities the bulk of the labour is supplied by Negroes, and much of the retail trade is conducted by Asiatics. The European colonists are a small dominant caste.

It is only in the Union of South Africa that the Whites are in sufficient numbers to form a considerable proportion in the population; but their future position, even in South Africa, is uncertain. There is no doubt of the suitability of the South African climate for Europeans. It has been the home of a large colony for more than a century, and the white

[1] The general election in South Africa, June 1924, shows the growing strength of the movement in favour of segregation.

Afrikander population is robust and efficient. But the maintenance of the white supremacy and even of a white Afrikander people is doubtful.

The population of the Union of South Africa in 1922 included 1,550,578 Whites and 5,504,580 coloured people; so the latter exceed the white by $3\frac{1}{2}$ to 1 and are increasing the faster. The coloured race is in especial excess in Natal, where Indian coolies supply the bulk of the labour in agriculture, industry, and retail trade. In the rest of the Union the coloured excess is that of the Negro. The white dominion may be maintained either by a small oligarchy managing black labour; or by white workers remaining in sufficient number to keep control under a Parliamentary government.

The oligarchic plan, which is the ideal of the Capitalists, hopes for the development of South Africa on the lines adopted in India until recent years. This system seems, however, to have little more chance of permanence in South Africa than in India. The measures introduced to strengthen it led Booker Washington to condemn the native policy of parts of the British Empire as worse than that of the United States. The rule of South Africa by a minority of white men is threatened by the uprise of an active Negro party which, with the support of the Ethiopian Church, demands its full share in the government of the country. This aggressive South African party, largely inspired from the United States, is likely to increase in numbers and influence. It may be controlled so long as there remains in the country a large number of comfortably circumstanced white labourers. The fundamental difficulty in South Africa is, however, the position of the 'poor Whites'; they form a class who are apt to interbreed with the Negroes and increase the percentage of half-castes. Many of the poorer white men have been forced to take work which is despised by the better class of black labourers; and the spectre in South Africa is the steady replacement of white workers by Negroes and half-castes in the skilled occupations. The difference in South Africa between visits in 1893 and 1905 which impressed me as most significant was that all the farriery, which in the former year had been done by Whites, had passed to the Blacks. This process has gone so far that it threatens the existence of white labour in South Africa, and the Capitalist attitude to it has led to the alliance of the Nationalist and Labour Parties. One of the main issues in contemporary South African politics is the segregation of the Negroes and Asiatics. The Nationalists accept the conclusion that the white man cannot compete on equal terms with the natives and Asiatics in manual labour. The wages for white labour varies from 10s. to 30s. a day; while that of a native adult varies from 6s. to 30s. a month. The pay of native domestic servants is the same, with the addition of food. The white man in South Africa cannot live on the same wages as the blacks. As the Negro becomes better educated and enters trade after trade, his white competitor must withdraw or reduce his standard of living to a level which involves ultimate demoralization. Some of the supporters of the Capitalist party admit these facts and consider the fusion of the black and white races at the Cape inevitable.

The Nationalists reject this pessimistic conclusion. They recognize that it can only be avoided by maintaining the distinction between the two races, which are most liable to commingling among the poorer classes. The Nationalist programme therefore includes the policy of segregation, which is opposed by the Capitalists, on the ground that it is an anti-Capitalist

measure and would raise the cost of labour. General Hertzog and his party, however, insist that some policy of segregation affords the only chance of maintaining the position of the white man in South Africa. The segregation policy in defence of the Whites seems fully justified by its long adoption in the interest of the natives. Thus Basutoland and the Transkei Territory in the east of Cape Colony are reserved for the natives; no European can settle in them without the express permission of the Governor-General. As white labour is excluded from some parts of South Africa in the interest of the Negro, it would seem only fair that the Whites should have a corresponding advantage elsewhere and especially in districts which were practically unoccupied until the Europeans entered them. According to one plan of segregation the natives should have a privileged position throughout the eastern lowlands of Cape Colony and Natal, and in some eastern districts in the Orange Free State and the Transvaal; some parts of this division of the country should be reserved for the coloured races, and no white people allowed to acquire land or an interest in land within them. In compensation for this restriction certain occupations and some areas should be reserved for the Whites in the western parts of Cape Colony, of the Orange River Colony, and of the Transvaal. The principle of segregation was approved by the Natives Land Act of 1913, but it has obvious difficulties. The British residents in South Africa deplore much in the Afrikander Nationalist programme; but its policy of segregation appears to advance the only plan by which South Africa can be developed as the permanent home of a large population of the European race.

V. Tropical Colonization and the Future of Australia.

We have seen therefore that in North America the presence of the Negro has introduced problems of inscrutable perplexity; that in South America a mixed race is in firm possession; that in Africa as a whole the white man has no chance as a colonist; and that in South Africa his future depends on some complex measure of segregation. In Asia only in the north and north-west has the white man any prospect of permanent dominion. In contrast to these restrictions in Australia the fundamental problem is the possibility of the occupation of the whole continent by the European race.

When the chief inrush of immigrants into Australia occurred after 1850, the belief was almost universal that the natural home of the white man was in the temperate zones and that the torrid zone must be left to the coloured races. That policy was accordingly adopted by Australia and pursued for 50 years. The tropical districts were left open, with varying limitations, to Asiatic immigration. Few Asiatics, however, took advantage of this opportunity, though large numbers were eager to enter the cities and settlements in the south, where the European had done the pioneer work. In the north the Asiatics were a hindrance, as they were too few to help materially, and they were sufficient to discourage the entrance of white artisans.

In 1901 Australia, on Federation, found itself faced by two problems—the empty north which the open-to-Asia policy had not filled, and the disturbing effect of indentured coolies on white labour. The policy of excluding coloured people and working the northern plantations with white

labour was declared to be a physical and physiological impossibility. According to Mr. Benjamin Kidd ('Control of the Tropics,' 1898, p. 48), 'the attempt to acclimatize the white man in the Tropics must be recognized to be a blunder of the first magnitude. All experiments based upon the idea are mere idle and empty enterprises foredoomed to failure.' Lord Olivier's opinion is that 'Tropical countries are not suited for settlement by Whites. Europeans cannot labour and bring up families there.' Mr. R. W. Hornabrook declares that to send Whites from Europe to Tropical Australia 'is nothing short of a crime—it is worse, it will be murder.'

In 1907, in opposition to this traditional view, I remarked ('Australasia,' I., p. 15) that 'medical authorities on tropical climates seem now, however, to be coming to the opinion that this view is a popular prejudice which does not rest on an adequate foundation.' The evidence to that effect had been stated in a remarkable paper by Dr. L. W. Sambon, and endorsed by the late Sir Patrick Manson, and has been supported by the general trend of medical opinion during the past seventeen years. Thus a leading article in the 'Journal of Tropical Medicine' (15 January, 1919, pp. 15-16) proclaims 'Disease, not climate, the Enemy . . . If there is one thing which the study of tropical diseases has shown us, it is that disease, and not the climate, is the cause of this crippling of trade, of the necessity for frequent changes "home," involving expense and the employment of a large permanent staff to fill the gaps caused by sickness, and therefore lessening of profits. The legends, a "bad climate," an "unhealthy climate," are well-nigh expunged from tropical literature. All medical men familiar with the Tropics are cognizant of the fact that disease, and, what is more, preventable disease, is the cause of the bad name associated with any particular region of the Tropics.'

The general distribution of mankind is in such close agreement with the rule that the white race has settled in the temperate regions and left the tropics to the coloured races, that any policy inconsistent with that arrangement must be prepared to encounter a strong prepossession to the contrary. Nevertheless, that rule is inconsistent with so many facts that it is not a safe basis for a national policy. In America, for example, the whole continent, except for the Eskimo in the north, was occupied by dark coloured Mongolian tribes, in which, according to Flower and Lydekker ('Mammals,' 1891, p. 752), 'the colour of the skin, notwithstanding the enormous difference of the climate under which many members of the group exist, varies but little.' The most northerly part of Europe is occupied by a coloured race, the Lapps. In Africa the darkness of the skin does not always vary in accordance with distance from the Equator.

1.—Supposed Unfavourable Factors in Tropical Climate.

(*A*) *Heat.*—The belief in the unsuitability of the tropics for the white man rests on several considerations. Most importance is naturally attributed to the heat, as that is the essential difference between the tropical and other zones. Intense heat is regarded as injurious to people not protected by a dark skin. That view overlooks the automatic process by which the living body adjusts itself to temperatures even higher than occur in any climate on earth, and that would quickly cook it, if dead.

During some experiments by Sir Charles Blagden in 1774, Sir Joseph Banks remained in a room for seven minutes at a temperature of 211°: and Blagden subsequently stayed at the temperature of 260°, while eggs were roasted hard and beefsteaks cooked in a few minutes. White men work in furnaces and bakeries at 600° F., and if they can survive such temperatures even for short spells, they should be able to withstand the hottest climate on earth.

That heat is not the dangerous factor in the tropics is obvious from the well-known fact that the hottest areas are often the healthiest. Agra is hotter and healthier than Bombay, and the summer heat of Colorado is fiercer than that in the less healthy Mississippi Valley.

(*b*) *Moist Heat.*—As dry heat affords no explanation of the high mortality of some tropical localities, appeal was made to moist heat, and to the combination of heat and moisture marked by a high wet bulb temperature. At any temperature above blood heat the body is cooled only by the evaporation of perspiration, which does not take place in air saturated with moisture. Hence in the Townsville experiments ('Proc. R. Soc.,' B.xci, 1920, p. 121), a man placed in a room in which the wet bulb temperature rose from 98° to 102°, fainted in forty minutes. In a hot locality a dose of atropin, which suppresses perspiration, may be quickly fatal.

A wet bulb temperature higher than blood heat would be fatal to men, white or black; but no earthly climate has such temperatures. It was at first suggested that the limit of human activity was the wet bulb temperature of 73°. I have previously quoted [2] well authenticated records of miners working for four-hour spells for months at the wet bulb temperature of 80° to 90° in Hongkong, the Straits Settlements, Beaufort in Borneo, and Ocean Island in the Pacific. At all these places people, both white and coloured, survive these conditions. Hence the limit has been gradually raised and it is recognized that men can withstand wet bulb temperatures of 85°, though the power of work under such conditions is necessarily greatly reduced. The highest wet bulb temperature mentioned in Dr. Griffith Taylor's record at Port Darwin is 81°. The wet bulb data for North Australia are scanty; but there seems no reason to expect that any considerable areas have a more uncomfortable climate than Calcutta, to which Dr. Taylor compares the worst localities of tropical Australia. Calcutta is one of the healthiest cities in India, and has a large and vigorous European population, many of whom spend there the whole year.

Moist heat is trying and must be considered in judging climates from the standard of comfort and personal efficiency. The investigation of wet bulb temperatures—the significance of which was shown by Sir John Haldane, has been developed in reference to the textile industries by Dr. Leonard Hill and Dr. Boycott, to mining by Sir John Cadman, and to the conditions of tropical Australia by the work of Professor Osborne and has been illustrated by the ingenious climographs of Dr. G. Taylor—has yielded results of high practical value. But the wet bulb isotherm does not delimit the areas where the white man may live and work, and does not

[2] 'The Wet Bulb Thermometer and Tropical Colonization.' *Journ. Scott. Meteor. Soc.*, ser. 3, vol. xvi, 1912, pp. 3–9.

really affect the question of white *versus* black colonization, as there does not seem to be any reason to believe that black men could withstand a higher wet bulb temperature than white men. In answer to an inquiry on this question, Sir John Haldane replied that his impression on the contrary was that 'white men can usually stand more heat than black men,' and he reported the information given him that in places like the Red Sea the Clyde stokers stand the heat better than the Lascars, 'and, in fact, have constantly to carry the latter out and lay them on deck to cool.' Dr. C. J. Martin also informs me that there seems no physiological reason why the conditions indicated by a high wet bulb temperature should be more adverse to the white man than to the coloured races.

(*c*) *Monotony in Temperature.*—Another temperature factor that has been appealed to is that depressing equability of temperature which occurs on some tropical coasts. Excessive monotony in the weather is no doubt depressing and temperature changes have a stimulating beneficial effect. Extremes of cold and heat are still more inconvenient and trying, and a moderate equability is often advertised as an attractive feature in a climate. The equability of the oceanic climate is recognized as most favourable for many conditions of health. The areas over which extreme uniformity of temperature prevails throughout the year are, however, so restricted that this factor does not affect the problem of tropical settlement as a whole. With the exception of low tropical islands, places with monotonously equable climates are in positions whence a change may be secured by a visit to some neighbouring hill country.

(*d*) *Actinic Rays.*—A fourth factor to which much importance has been attached in connection with the tropical climate is the effect of the chemical rays of the sun. Great importance was once attached to the pernicious influence of the ultra-violet chemical rays of the sun on persons not protected by a dark skin. Residents in the tropics were therefore advised to line their clothes with orange-coloured fabrics to shield themselves from the chemically active rays. These views reached their extreme in the writings of Surgeon-Major C. E. Woodruff in 1905 on the 'Effects of Tropical Light on White Men.' Woodruff held that the actinic rays of the sun are so inimical to the white man that they inhibit his permanent settlement within 45° of the Equator. He therefore regarded the tip of Patagonia as the only area in the Southern Hemisphere fit for white occupation. The temporary stagnancy of the population of Australia after the droughts of 1900-1902 he regarded as evidence that the native-born white Australian and delicate New Zealander were wasting away through physical decay due to the enfeebling sunshine, just as the health of American and European children was being ruined by the 'daft' practice, as he called it, of flooding schoolrooms and nurseries with streams of light. Woodruff's conclusions have naturally been disregarded.

Any deleterious effects of the chemical rays of the sun may be avoided by the use of appropriate clothes, and physical considerations suggest that a black skin should afford less protection than a white skin. Any injury that may be wrought by powerful sunshine, according to Aron's work in the Philippines, is due to the heat rays at the red end of the spectrum and not to the chemical rays. The modern lauded system of heliotherapy is based on the belief that strong sunshine is a powerful curative agency.

(*e*) *Miscellaneous Factors.*—The four previously considered factors have the advantage that they can be readily understood and tested; but as they have failed to provide any basis for the unsuitability of the tropics for the white man, the appeal has been shifted to a complex of tropical influences, including a rise of body temperature, the lessened activity of lung and kidney, and nervous disturbances. Dirt and disease and carelessly prepared food are also mentioned, though they are due to human agencies. The physiological effects of the tropical climate in this indictment are contradicted by high authorities. The rise in body temperature is emphatically denied amongst others by Breinl and Young from observations in Queensland, and by Chamberlain on the basis of extensive observations on American soldiers in the Philippines. A slight rise may occur in passing from the temperate regions to the tropics, but it is soon recovered; and Shaklee reports from his experiments on monkeys at Manila that 'the healthy white men may be readily acclimatized to the conditions named—that is, to the tropical climate at its worst.' Shaklee adds that the most important factor in acclimatization is diet.

The asserted ill-effects of the tropics on respiration appear to have no more solid basis. Professor Osborne found at Melbourne that the rate of respiration was increased on the hottest days, and his observations agree with those of Chamberlain in Manila. So far from the tropical conditions being injurious to the kidneys, it is asserted, as by Dr. A. B. Balfour, that there is less trouble with that organ in tropical than in temperate climates. The apparently inconsistent observations on the action of the kidneys between various tropical localities and people, may be explained by differences in diet.

The remaining charges against the tropical climate are insignificant, or not based on climatic elements, or are indefinite. Some of the alleged factors are trivial, such as the liability to various skin diseases owing to a change in the skin reaction; for if the white man allows himself to be kept out of any country by such a cause he does not deserve to get in. The hygienic troubles due to association with an insanitary people are sometimes adduced; but they are not an element in climate and would not operate in a land reserved for white people. The remaining factors rest on ill-defined nervous ailments which are more likely to be due to domestic difficulties than to climate. These nervous troubles fall mainly on the women who have the strain of disciplining native servants into conformity with British ways. Nervous disorders are said to be worst in hot, dry, dusty regions which in the tropics are generally regarded as the most healthy, except to those whose constitutions require a moist atmosphere.

2.—Medical Opinion.

Medical opinion has gone far towards the general adoption of the conclusion that there is nothing in climate to prohibit the white man from settling in the tropics.

As an example of a recent authoritative verdict may be quoted the report of a sub-committee appointed in 1914 by the Australian Medical Congress to investigate the medical aspects of tropical settlement. After extensive inquiries, the comparison of the blood of children born and bred in the tropics with those of the temperate regions, and other evidence, the

sub-committee reported in 1920 as follows : 'After mature consideration of these and other sources of information embodying the results of long and varied professional experience and observation in the Australian Tropics, the sub-committee is unable to find anything pointing to the existence of inherent or insuperable obstacles in the way of the permanent occupation of Tropical Australia by a healthy indigenous white race. They consider that the whole question of successful development and settlement of Tropical Australia by white races is fundamentally a question of applied public health in the modern sense . . . They consider that the absence of semi-civilized coloured peoples in Northern Australia simplifies the problem very greatly.'

3.—Improvements by Public Sanitation.

The trend of medical opinion to the view that there is no physiological reason why the white race should not inhabit the tropics may lead to a change similar to that regarding some localities in the temperate zones, which were formerly regarded as death-traps and are now popular health resorts. The island of Walcheren, on the coast of one of the most densely peopled countries in Europe and only thirty miles from so fashionable a watering-place as Ostend, had a century and a quarter ago one of the most deadly climates in Europe. The largest army which had ever left the British islands landed there in 1809. Napoleon did not think it worth powder and shot. 'Only keep them in check,' was his order, 'and the bad air and fevers peculiar to the country will soon destroy the army.' Napoleon's judgment was justified. The force of 70,000 men disembarked on July 31 and August 1. By October 10, according to Sir Ranald Martin, 142 per thousand were dead of disease, and 587 per thousand were ill.

Algeria is now a trusted sanatorium. Yet disease annually swept away 7 per cent. of the French army that conquered it. Sir A. M. Tulloch remarked that if the French Government had realized the significance of that mortality 'it would never have entered on the wild speculation of cultivating the soil of Africa by Europeans, nor have wasted a hundred millions sterling with no other result than the loss of 100,000 men, who have fallen victims to the climate of that country.' The same change of view has taken place in reference to some tropical localities. The deadliness of the Spanish Main to our armies was described by Samuel Johnson. 'The attack on Cartagena,' he said, 'is yet remembered, where the Spaniards from the ramparts saw their invaders destroyed by the hostility of the elements ; poisoned by the air, and crippled by the dews ; where every hour swept away battalions ; and in the three days that passed between the descent and re-embarkation half an army perished. In the last war the Havanna was taken, at what expense is too well remembered. May my country be never cursed with such another conquest.' Yet Havanna, under American administration, has become one of the healthiest cities in the world.

Sir John Moore, when Governor of St. Lucia (1796), wrote home that it is not the climate that kills, but mismanagement. His insight has been demonstrated in the same region. The French attempt to build the Panama Canal was defeated by disease. Discovery of its nature enabled

the late Surgeon-General Gorgas to secure for the 10,000 men, women and children in the canal construction camps, in spite of the high humid heat, as good health as they would have had in the United States. Gorgas claimed that the results at Panama 'will be generally received as a demonstration that the white man can live and thrive in the tropics.' Gorgas realized that the results for the future are even more momentous. He predicted that as 'the amount of wealth which can be produced in the tropics for a given amount of labour is so much larger than that which can be produced in the temperate zone by the same amount of labour, that the attraction for the white man to emigrate to the tropics will be very great when it is appreciated that he can be made safe as to his health conditions at small expense. When the great valleys of the Amazon and of the Congo are occupied by a white population more food will be produced in these regions than is now produced in all the rest of the inhabited world.'

4.—Old-established European Settlements in the Tropics.

Similar improvements are in progress elsewhere and explain why some white colonies have existed for long periods in the tropics without physical deterioration.

Two distinguished authorities on Equatorial South America—A. Russel Wallace and Richard Spruce—agree that under the Equator in Ecuador and northern Peru there are many Spaniards whose ancestors have lived there for centuries. Spruce says that some of the Spanish families at Guayaquil (lat. 2°13′S.) are pure in race, and have maintained their physical fitness after centuries of residence under the Equator. In the West Indies there are various old-established European colonies. The island of Saba (17°38′N.) was occupied by the Dutch in 1644. The descendants of the original settlers still occupy it and, apart from some effects of in-breeding, are reported to be healthy and vigorous and incontestably pure in race. Some of the German colonies in Brazil are within the tropics, and though established as early as 1847 the settlers are in good physical condition; at Santa Katharina, in a low-lying part of the coast just south of the tropics, the 85,000 Germans are reported to have better health than the natives.

The European settlement in the tropics in the small island of Kissa, off Timor, is especially remarkable for its long survival, despite its small numbers and unfavourable circumstances. Eight Dutch soldiers and their wives were landed on Kissa in 1665 to hold it against the Portuguese. They were forgotten, but they established themselves, and their descendants now number over 300. The Admiralty Pilot describes the island as unhealthy and feverish. Nevertheless, the Dutch colony is said to be healthy, and many of its members have fair hair, blue eyes and blonde complexions. They retain the names of the original settlers, but they have lost their Dutch language and religion, and have adopted many native ways of life. A Dutch missionary, Rinnooij, has referred to the settlers as mestizos, *i.e.* half-castes, and states that the soldiers took wives from the daughters of the land. His statements are quite inconsistent with the later and more detailed account by Professor Macmillan Brown. If the women of the colony had always been natives of Kissa, the survival of the light hair, eye, and skin appears inexplicable. Hence, though Macmillan Brown may have underrated the Malay infusion, it

appears probable that this colony is mainly of Dutch stock, and has kept its physical characteristics undamaged by the two-and-a-half centuries of residence only eight degrees from the Equator.

Many cases of the decadence or extinction of ill-placed European colonies in the tropics are of course known, such as the Bahamas, as described by Professor Ellsworth Huntington. Such misfortunes have been regarded as evidence of the inevitably injurious effect of the tropical climate on white men. But if white colonies have maintained good health in the tropics, the failures are not caused by climate alone.

5.—The Development of Tropical Australia.

The experience of colonization in tropical Australia is limited to about seventy years; but it affords no ground for the expectation that the ultimate effects on the white race will be detrimental.

(*a*) *Vital Statistics in Queensland.*—In Queensland, most of which is tropical, the death-rate is lower than in any European country and is lower than in most of extra-tropical Australia. In the six years 1915-21, according to the statistics in the Australian Year-book (No. 15, 1922, p. 99), the crude death-rate in Queensland was the lowest in the six Australian States for one year, and fourth of the six States in three years, and the fifth in three; it was not once the highest. In the same six years the infantile death-rate was lowest in Queensland in three years, and the second lowest in two others. According to the same authority, by Index of Mortality (*i.e.* the death-rate in proportion to the ages of the community), Queensland was in 1921 the second State in order of merit, being inferior only by ·03 to New South Wales, the State most favoured in this respect.

The physical vigour of the Queenslander is shown by his athletic prowess, and by the low rejection-rate of recruits from that State for the Citizen Army. The longevity in Queensland may be judged by the experience of the life assurance offices. It has often been asserted that assurance rates show that tropical climates are unhealthy. Yet the chief actuary for the greatest Australian assurance company, the Australian Mutual Provident Society, reported to the Committee of the Australian Medical Congress, 'I have no hesitation in saying that as far as we know at present there is no need for life assurance offices to treat proponents who live in North Queensland differently from proponents who live in other parts of Australia.'

Physical and mental degeneration in a people living under unfavourable conditions would probably be most readily observed in the children. To use this clue I asked the Queensland Education Department whether its inspectors had noticed any unfavourable symptoms among the children in the most tropical of its northern schools. The Department replied that on the contrary its schools at Cairns and Cooktown, two of the most northern towns, are exceptionally efficient and one of them is sometimes the leading school in the State.

(*b*) *Northern Territory.*—The great success of Queensland, although more than half the State is within the tropics, renders the more striking the failure of the adjacent Northern Territory of Australia, of which the records are disappointing. Agriculture has declined; the Government demonstration forms have been reduced to native reserves; the meat

works have been closed; the population has fallen in numbers; and mining production has become insignificant. The present state of the Territory has been adduced as evidence of the futility of trying to develop a tropical land by white labour. Its failure was not, however, due to the White Australia policy, which was introduced after the failure was complete, but to geographical disadvantages not yet surmounted. The Territory, before 1901, was open to Asiatic immigration, but the hope that it would be adequately peopled from Asia was not fulfilled. Its population was largest in 1888, and then it was only 7,533. The Chinese were most numerous during the construction of the Pine Creek Railway in 1887-8; their numbers were 4,141 in 1890, and fell to 2,928 in 1900, and to 1,387 in 1910. High expectations had been formed of the Northern Territory from its tropical position, and it was hoped to become an Eldorado as an Australian Java. It was fondly called 'the Land of the Dawning,' and described as containing limitless areas of, for some purposes, the best land in the world. Searcy, for example, declared that it includes 'land equal in size to the islands of Java and Madura, suitable for any sort of tropical agriculture.'

Careful comparison with Java would, however, have served as a warning that easy prosperity was impossible. Java has been a densely-peopled, highly-cultivated island, with an advanced indigenous civilization since prehistoric times. The Northern Territory of Australia has been throughout the same period practically an unoccupied deserted waste. Java has rich widespread soils and a convenient rainfall. The Northern Territory has in the main poor soils, and its rain all falls during five, and most of it during three months, leaving the land parched and scorched for seven months every year. The water from the wells is alkaline and the supply too small for extensive irrigation, while land irrigated with it is soon rendered sterile.

Poorness of soil, unsuitable distribution of rainfall, and inaccessibility of position explain the backwardness of the Northern Territory. Dr. Jensen, the former Government Geologist for the Territory, describes the agricultural resources as 'circumscribed,' the rich patches of lowland soil being 'so wretchedly small and so few,' while the larger areas are situated where they could 'only be successfully cultivated by the installation of great irrigation schemes, which are not warranted, while equally good areas are available in other States with better climate, facilities, and markets.' Great hopes are based on cotton, despite Dr. Jensen's pessimism regarding it. Its profitable cultivation appears dependent upon the establishment of a protected cotton manufacture in Australia, which would secure a market for the crop at a price that would pay for the high cost of picking.

The remedy for the failure of the Northern Territory lies not in another attempt with Asiatics, but in the removal of the isolation of the Territory. Two routes for railway connection are available—the completion of the Mid-Continental Line to South Australia, or the construction of a line past the Gulf of Carpentaria to Queensland. The route to Adelaide appears the more promising, as it would connect two areas so different that they would be complementary and not competitive; whereas the railway to Queensland would run through one climatic zone and would connect districts which yield the same products. No special advantage would accrue to

Queensland from opening another tropical area; whereas a railway to Adelaide would connect localities in different climatic belts. While the only access to Port Darwin from the capital cities of Australia is by a voyage of 3,000 or 4,000 miles remote from either of the main steamer routes to Australia, the satisfactory development of the Northern Territory will be impossible.

(c) *Queensland and the Sugar Industry.*—Queensland in contrast to the Northern Territory has made firm progress; the population has continued to increase; and though at first coloured labour was introduced, the proportion of the Asiatic population in 1911 was only 1·47 per cent., and of the Polynesian only ·29 per cent.

The numbers of coloured labourers in Queensland were too small seriously to affect the population, but they were sufficient to be a constant irritant and source of uncertainty in the local labour market. This trouble led, in 1900, to the prohibition of indentured coolie labour throughout Australia. This decision was supported by the great majority of the Queensland people in spite of the most emphatic warnings of disaster.

Some of the sugar estates are in localities with extreme tropical climates; and the Queensland Chambers of Commerce, members of Parliament, Farmers' Associations, and bishops, declared that sugar could not be grown by white labour. The difficulty was said to be an absolute physical impossibility and not merely economic, so that the stoppage of Kanaka labour meant the certain death of the Australian sugar industry. At that time the sugar plantations were not prosperous, and exclusion of the Kanakas was supported on the ground that so struggling and unprofitable a branch of agriculture had better die rather than upset the policy of the whole continent.

The Bill for the exclusion of the South Sea islanders was therefore enacted and the sugar industry left dependent on white labour. In spite, however, of the confident predictions of the experts and their friends the industry has gone on and been more successful than when run by coloured labour.[3] The returns of the industry are irregular. In some seasons the yield is good, as in the record year 1917-18, and more land is planted. An unfavourable planting season reduces the area under cultivation and the yields in the second and third years later. Comparisons of single years are uncertain; but the following table shows that the areas under cane and the quantity of sugar produced have increased greatly since the industry became dependent on white labour.

[3] I gave an account of the progress of white labour on the plantations up to 1908, after a visit to four of the chief sugar-producing districts, in the *Nineteenth Century*, February, 1910, pp. 368–380; and in the *Proc. R. Phil. Soc.*, Glasgow, vol. xliii, 1912, pp. 182–194.

QUEENSLAND SUGAR PRODUCTION.

—	Acreage	Cane, Tons	Sugar, Tons
1900–1	108,535	848,328	92,554
1906–10	134,107	1,415,745	152,259
1910–11	141,779	1,840,447	210,756
1916–17	167,221	1,579,514	176,973
1917–18	175,762	2,704,211	307,714
1918–19	160,534	1,674,829	189,978
1919–20	148,469	1,258,760	162,136
1920–21	162,619	1,339,455	167,401

[The sugar yield for 1922 is reported as 188,000 tons.]

It may be said that the increase in output and area ought to have been larger, but it should be understood that the Queensland sugar industry is not situated under specially favourable natural circumstances, as the land suitable for sugar occurs in relatively small isolated areas. Hence, the cane has to be treated at forty scattered mills, and the work cannot be done as economically as if concentrated in a few places.

The Australian adoption of white labour for its sugar plantations has been the greatest contribution yet made to the practical solution of the problem whether the white man can do agricultural work in the tropics. The experiment shows that white labour can be employed successfully in such an ultra-tropical industry as sugar cultivation in even the ultra-tropical climate of the Queensland coastlands, provided the settlers are protected from infectious disease and from the competition of people with lower standards of life.

6.—Rate of Progress and the Drawbacks of the Tropical Climate.

The results of the Australian decision in 1901 to discard coloured labour have shown that the daring policy then begun is practicable ; but it may render development slow and costly. The slowness of the progress may be amply compensated by its sureness in the end. Some American authorities on migration (*cf.* H. P. Fairchild, 'Immigration,' 1923, pp. 215–225, 342) maintain that immigration during the past half-century into America has not added to the total population, as it has lowered the birth-rate of the older American stock, and merely substituted a very large foreign for a native element that would otherwise have come into being. An immediate increase caused by the introduction of a large number of Asiatics might mean a reduction in the European proportion in the Australian race, with in the end no increase in the total population.

The conclusion that white settlement of the tropics is possible should not lead to the drawbacks of a tropical climate being overlooked. The conditions where the wet bulb temperatures are high are uncomfortable and unfavourable to mental and physical activity. People who are not keenly interested in their work should avoid the tropics. Ellsworth Huntington in a valuable series of works has called attention to many facts which show the dependence of Western civilization on the stimulating nature of the temperate climate, for the frequent changes in temperature and wind are conducive to alertness and general efficiency.

The enervating effect of the tropical climate is no doubt counterbalanced by various compensations. Man needs less in food, fuel, clothing, and housing, while the same amount of exertion will produce a more luxuriant and valuable crop. The supremely fertile tropical regions have, however, usually a hot muggy climate, which is not attractive to Europeans while areas with less trying conditions are available. Northern Australia, even if it were not hampered by a high proportion of poor land, would naturally develop slowly, just as in Canada the Northern Territory and the rocky backwoods have lagged behind the St. Lawrence basin and the rich-soiled western plains.

The natural development of tropical Australia would be by overflow from the south when that part of the continent is more adequately peopled. Progress could be best aided by opening routes to tempt those with pioneering instincts to wander northward. This process may be considered too slow by those who consider the immediate occupation of tropical Australia a political necessity in order to prevent its annexation by some Asiatic Power; but the alarms based on Asiatic designs against Australia ignore the vast empty areas in Asia, the rich lands that could be more easily acquired in the Eastern Archipelago, and the persistence with which the people of south-eastern Asia have shunned areas in their own continent under geographical conditions corresponding to those of most of tropical Australia.

7.—Conclusion.

The conclusion that the white man is not physiologically disqualified from manual labour in the tropics and may colonize any part of Australia simplifies inter-racial problems, as it provides an additional outlet and spacious home for the European race.

The preceding survey of the position where the three main races meet in intimate association indicates that the world will have a happier and brighter future if it can avoid the co-residence in mass of members of the different primary divisions of mankind. Individual association and contact should secure for each race the benefit of the intellectual, artistic, and moral talents of the others; while industrial co-operation should aid each nation to make the best use of the land in its care.

The world has reached its present position by the help of each of its three great races, and it still needs the special qualities of each of them. The contemplative Asiatic founded all the chief religions, the ethical basis of civilization. The artistic Negro probably gave the world the gift of iron, the material basis of civilization. The administrative genius of the European race has organized the brain power of the world to its most original and constructive efforts. The affectionate, emotional Negro, the docile, diligent Asiatic, and the inventive, enterprising European do not, however, work at their best when associated in mass. That association is attended with serious difficulties; for race amalgamation, which is the natural sequel, is abhorrent to many nations, and the intermarriage of widely different breeds, according to many authorities, produces inferior offspring. The policy of co-residence with racial integrity has failed to secure harmonious progress in North America and South Africa. The development of the best qualities of the three races requires their separate

existence as a whole, with opportunities for individual association and co-operation.

In view of the inter-racial difficulties that have developed wherever the races are intermingled, Australia will throw away a unique opportunity if it fails to make a patient effort to secure the whole continent as the home of the white race.

SECTION F.—ECONOMIC SCIENCE AND STATISTICS.

A RETROSPECT OF FREE TRADE DOCTRINE.

ADDRESS BY

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A man would be singularly insensible who could stand in this place without emotion after an absence from Toronto of well-nigh a third of a century; and dead indeed to feeling when, across that long interval, he could look back to four years of such experience as fell to me in this City and Dominion between 1888 and 1892. The place where a man first makes a settled home; where he first knows the joys and anxieties of family life; where he meets with abundant daily kindness in unfamiliar surroundings; can never cease to be affectionately remembered. And when it is the place where, young and English as he was, he was entrusted by Canadians with the task of organising a new department in a University already important and destined to be great, and in a Dominion where he was the first Professor of Political Economy, his satisfaction at finding himself unexpectedly in the scene of his early endeavours can be readily understood. And how much has happened since then! The material development of the Dominion will be the theme of many papers in this and other sections of the Association. On the academic side one notes that where there were two considerable universities there are now half a dozen or more; that where there was one professorial economist there are now a score. I remember with what inward trepidation I confronted my duties. It is fortunate that in youth, when one wants it most, one has a better conceit of oneself than in maturer years. But this little credit I can take to myself: even in the earliest days of my association with young men and women in the University of Toronto, I was never so blind as not to realise that here, in Canada, was the future home of a great nationality, with its own vigorous patriotism and its own confident outlook on the future.

Political Economy is now old enough to have reached the stage of retrospect. I shall take advantage of this circumstance, and I shall ask you to consider with me a well-rounded body of economic ideas during a well-marked period. The body of ideas shall be the general English doctrine of International Free Trade. And the period shall be the century approximately which followed the publication of the 'Wealth of Nations.' It is well marked in economic literature; for it covers the time which elapsed before the new developments made themselves felt which are associated with the names of Jevons and Cliffe Leslie. And it is well marked externally; for it came to an end before England had lost the commercial supremacy due to its early utilisation of coal and iron, and before English agriculture had

begun to be seriously affected by the cheap grain of the new countries. The doctrine was imposing by its simplicity and symmetry. It consisted of a few easily intelligible propositions, following readily one upon the other, and so sweeping in their range, and so optimistic in their implications, that they dwarfed all cautious exceptions and qualifications. No great English economist indeed—neither Adam Smith, nor Malthus, nor Ricardo, nor John Stuart Mill—was, in fact, an out-and-out free trader so far as practical application was concerned. Still less were they resolute non-interventionists over the whole range of economic life; for entirely consistent and unlimited *laissez-faire* we should have to go to their more severely logical French contemporaries. But they based themselves on certain general principles, and they drew from them general conclusions which practical politicians could easily employ to justify an absoluteness of policy from which they shrank themselves; they were reverenced as spiritual masters, whose occasional aberrations must be lamented or disregarded.

I shall endeavour first to set forth the doctrine in a number of brief propositions; then to make some observations under each head. The several theses will not be found quite so consecutively stated in any of the authoritative writings, and I pursue this method partly for ease of subsequent reference. But it will be agreed, I expect, that they fairly represent the general structure of thought on which rested the whole edifice.

These, then, are the propositions:

1. That Nature is beneficent. By 'Nature' is meant, in this connexion, the operation of the unpremeditated instincts, desires, passions of individual men and women. Any restriction of this operation by an authority outside the individual is 'artificial,' and therefore bad. Nature, so understood, is the scheme of things created by God. And since God, with infinite wisdom, has established this mechanism for the fulfilment of His purposes, Nature is, as it were, His Vicegerent, and the 'laws' of its action are 'providential.' But theistic language may be dropped, and the theistic conception even repudiated. And then 'Nature' remains as self-directed, and beneficent of itself; and the reverence with which it is regarded amounts in effect to deification.

This does not mean that every particular action dictated by a 'natural' passion is, considered in itself, morally commendable: it may even be 'shocking' to the moral sense. But the 'natural' impulses work out on the whole for good, with only such a minimum amount of evil as is involved in the execution of the whole design. The wisdom of God is displayed in the folly of men: by an Invisible Hand they are led to promote salutary results which are no part of their intention.

2. That individual Freedom or Liberty is in itself a good thing. This is a corollary from, or rather, only another expression for, the preceding proposition. For by 'freedom' or 'liberty' is meant the right to pursue unchecked the instincts or passions implanted by Nature. It is true that this liberty must respect the like liberty of others; and reflection on what is involved in this qualification might suggest some doubt as to the validity of the proposition it qualifies. But this line of thought was left for subsequent generations.

So long as the purpose of the social union is conceived of as the enabling of the individual to follow his 'natural' desires, their pursuit is regarded

as a 'natural right.' Violations of natural liberty are therefore inherently 'unjust.' But the conception of inherent individual rights may be repudiated; and then interference may be condemned simply on the ground that it is impolitic from the point of view of social utility. In any case the presumption is held to be on the side of 'liberty.' The term, first 'natural liberty' and then 'liberty' or 'freedom' without the adjective, could thus be used, without formal argument, as bringing with it a whole atmosphere of commendation; while 'interference' or 'artificial' brought at once, and without attempt at formal proof, a whole atmosphere of disapproval.

3. That society is nothing more than an aggregate collection of individuals. Accordingly the wealth, the advantage, the profit of society as a whole is but the sum of the wealths, the advantages, the profits of the individuals composing it.

4. That every individual left to himself pursues his own interest his own way, and knows it better than anybody else. Accordingly, absence of restriction on the individual is the best means of serving the community. Social interest is identical with individual interest.

5. That every country has certain natural advantages. Left to themselves individuals will exert themselves in the directions to which these advantages point. It is, therefore, for the benefit of a country or nation that they should be left free to do so.

6. That in each country there is at any moment a certain given supply of capital and labour, which cannot be increased by any action of the State. Since, left to themselves, they will spontaneously flow into the employments most advantageous to themselves and consequently to the country, any action of a public authority which directs them towards employments to which they would not of themselves go, or keeps them in industries which they would otherwise leave, involves loss to the country.

7. That if another country can supply certain commodities more cheaply, it follows that that country must possess advantages which the importing country does not enjoy. Since these imports must be paid for by exports, they must be paid for by commodities in the production of which the importing country has an advantage. Each country thus obtains what it wants with the least expenditure of labour or capital, *i.e.* most cheaply, and benefits by international division of labour. Since the advantages in question are of divine appointment, to refuse to take the fullest advantage of international division of labour is to fly in the face of Providence. If the theistic conception is dropped, and the argument is based on utility, the offence is the equally serious one of disregarding common sense.

8. That the national capital and labour can be transferred from one occupation to another. If an existing industry cannot be profitably carried on owing to foreign competition, the capital and labour involved can be transferred to some other manufacture within the country, and must inevitably be so transferred in order to provide the additional commodities necessary to pay for the imports. That the foreign country will—indeed, must—take commodities in return for what it sends, proves that in some exportable commodities the home country has an advantage. The destruction of a native industry is in itself a proof that it has no economic right to exist.

9. That, left to themselves, people will buy whatever they want at the cheapest price. This, therefore, must be their interest. And since the State is a collection of consumers, and individual interest is social interest, the ultimate criterion of the interest of the State is the interest of consumers.

In these nine propositions and their corollaries consists the whole of the generally accepted economic doctrine of the century which followed upon the great work of Smith. That they were held to be sufficient and decisive as late as 1878 is very authoritatively stated in the most widely circulated of treatises on the subject—the lectures of Professor Fawcett, which appeared in that year and quickly passed through several editions. 'All the most effective arguments,' he remarks, 'that can now be urged in favour of free trade had . . . been stated with the most admirable clearness and force by Adam Smith, Ricardo, and other economists. In the pages of these writers are to be found many passages which furnish the best reply that can be made to the modern opponents of free trade.' [1]

1, 2. The first two of the propositions—that Nature is beneficent, and that Nature consists in the unrestricted freedom of every individual to pursue his personal desires and interest in his own way—were inextricably associated in the minds of the first generation of English economists. It will be sufficient for our purpose to consider them together, under the term Adam Smith himself employs in a famous passage. When all preference or restraint, he says, is completely taken away, it gives place to 'the simple system of Natural Liberty.' [2] The context shows that by 'system' Smith means both the doctrine and the condition of things which results when the doctrine is put into effect.

We need not spend much time over the genesis of this doctrine. If we knew nothing of Adam Smith but the 'Wealth of Nations,' and took care only to read certain parts of it, some sort of case might be made out for the view that the doctrine was for Adam Smith an induction from experience: this and this and this case of interference with natural liberty, we might suppose him to have found, were demonstrably harmful, and therefore, he concluded, all interference with natural liberty was harmful. No one need deny that some of the instances he cites did lend support to this contention; nor need anyone deny also that the contemporary system of governmental or corporate regulation was ill adapted to the needs of the capitalistic era then opening. But it would be to disregard all Adam Smith's antecedents as a philosopher; all that we know of the history and transformation of the conception of 'Nature' from the Greek thinkers downward; all the evident affiliation of Smith with his predecessor Hutcheson, and of both with Shaftesbury; and in particular it would be to ignore the essential unity of the 'Wealth of Nations' with Smith's other work, the 'Theory of Moral Sentiments,' to refuse to recognise that Smith took over the doctrine of Natural Liberty from current theology and moral philosophy. The movement of his mind was fundamentally deductive: natural liberty, he started with believing, is beneficent; he expected therefore to find all interferences with it harmful, and he had no difficulty in discovering instances.

[1] *Free Trade and Protection*, 6th ed. (1885), p. 3.
[2] *Wealth of Nations*, Bk. IV., ch. ix. (ed. Rogers, ii., 272).

Buckle has asserted that Adam Smith's greatness is shown by his basing everything in his Moral Philosophy upon Sympathy and everything in his Economics upon Self-interest, and by his leaving his readers to make the necessary adjustment between them. It would be a doubtful compliment, if true; but no one can suppose it to be true who has read his two works attentively. I am not concerned to maintain Smith's philosophical consistency; my own impression, for what it is worth, is that his system of moral philosophy is by no means water-tight. But Smith himself, down to the end of his life, thought of his Moral Philosophy and his Economics as forming one whole.[3] And the recurrence of certain characteristic phrases in the second of his books shows clearly enough that he looked back on his earlier work as laying his philosophical foundation.

It is so necessary that this should be realised if we are to judge fairly some of his successors, that I will ask you to let me adduce one or two pieces of evidence.

Perhaps the most formal statement of his belief will be found in the generalisations to which he is led when considering the social utility of 'resentment'—a passion which, he says, is 'commonly regarded' as 'odious.' Odious though it be, it is, he holds, useful; and it is useful, in spite of the fact that it is not itself the outcome of conscious reasoning. For, as the very existence of society is at stake, 'the Author of Nature has not entrusted it to man's reason to find out . . . the proper means of attaining this end.' He then proceeds to generalise—substituting a personified Nature for her Author. 'The economy of Nature is in this respect exactly of a piece with what it is upon *many other occasions*. With regard to *all* those ends which, upon account of their peculiar importance may be regarded, if such an expression is allowable, as the favourite ends of Nature, she has *constantly* not only endowed mankind with an appetite for the end which she proposes, but likewise with an appetite for the means by which alone the end can be brought about, for their own sakes and independently of their tendency to produce it. Thus self-preservation and the propagation of the species are the great ends which Nature seems to have proposed in the formation of all animals. But . . . it has not been entrusted to the slow and uncertain determinations of our reason to find out the proper means of bringing them about. Nature has directed as to the greater part of these by *original and immediate instincts*. Hunger, thirst, the passion which unites the two sexes, the *love of pleasure* and the *dread of pain* prompt us to apply these means for their own sakes, and without any consideration of their tendency to those beneficent ends which the great Director of Nature intended to produce by them.' You will notice how he again falls back into theistic phraseology.[4]

Scotch caution abundantly shows itself in both of Smith's books; and the method of hedging implied in the insertion of 'upon many occasions' is highly characteristic.[5] But such hedging is never intended to give,

[3] Compare the last paragraph of the first edition (1759) of the *Moral Sentiments* with the Advertisement to the 6th edition (1790).

[4] This is in the long note at the end of *Moral Sentiments,* Part II., Sec. I., ch. v. (Ward, Lock & Co.'s Reprint, p. 71, under the title *Essays* . . . by Adam Smith).

[5] Even this qualification, it will be noticed, disappears with respect to 'all the favourite ends of Nature,' where she has 'constantly' pursued the policy described.

and does not really give, any serious qualification to the general proposition. This is amusingly illustrated by two parallel passages employing an identical phrase. In the one he is commenting on the respect which mankind has for success, for wealth and greatness. This respect might certainly seem to the moralist extravagant; if not, what Smith himself calls it, 'the great and universal cause of the corruption of our moral sentiments.' He continues, however, unperturbed: 'This great disorder in our moral sentiments is by no means without its utility; and we may on this, as well as on *many other occasions*, admire the wisdom of God even in the weakness and folly of man. Our admiration of success is founded upon the same principle with our respect for wealth and greatness and is equally necessary for establishing the distinction of ranks and the order of society.'[6]

In the other passage, Smith is commenting on the fact that 'the world judges by the event and not by the design.' This, again, might well seem to the moralist unsatisfactory. And so, indeed, it is; but it is all for a good end. 'Nature, when she implanted the seeds of this irregularity in the human breast, seems, *as upon all other occasions*, to have intended the happiness and perfection of the species. . . . That necessary rule of justice that men in this life are liable to punishment for their actions only . . . is founded upon this salutary and useful irregularity concerning merit and demerit, which at first sight appears so absurd and unaccountable. But *every* part of Nature, when attentively surveyed, equally demonstrates the *providential care* of its Author, and we may admire the wisdom and goodness of God even in the weakness and folly of men.'[7]

The truth is that Smith was bound by his general philosophical position to generalise, however frequently Scotch caution might check him for the moment. For if 'the happiness of mankind' was 'the original purpose intended by the Author of Nature,' and if Nature was conceived as Smith conceived it, then he was prepared to find, on an 'examination of the works of Nature,' that they seemed all 'intended to promote happiness and to guard against misery.'[8] Any apparent defects must be the irreducible minimum of evil necessary for the existence of the good.

> 'All Discord, Harmony not understood;
> All partial Evil, universal Good,'

as Pope has it.

As early as the date of his 'Moral Sentiments' Smith began to find his philosophic optimism confirmed in the economic sphere. 'Success in every sort of business' is 'the reward most proper for encouraging industry, prudence, and circumspection. . . . Wealth, and external honours are their proper recompense, and the recompense which they seldom fail of acquiring.' And thus, 'the general rules by which prosperity and adversity are commonly distributed . . . appear to be perfectly suited to the situation of mankind in this life.'[9] The 'pleasures of wealth,' it is true, are vastly exaggerated by the imagination; but 'it is well that Nature imposes upon

[6] The matter is considered at length in two places: Part I., Sec. III., ch. iii. (Reprint, p. 56); and Part VI., Sec. III. (Reprint, p. 224).

[7] Part II., Sec. III., ch. iii. 'Of the Final Cause of this Irregularity of Sentiments.' (Reprint, p. 96.)

[8] Part III., ch. v. (Reprint, p. 146.)

[9] *Ibid.* p. 147.

us in this manner. It is this deception which rouses and keeps in continual motion the industry of mankind.' [10]

One more quotation will enable us, by the help of a phrase which reappears in the 'Wealth of Nations,' to pass from the ethical to the economic treatise. It is the passage in which he explains how beneficial to society in general and the poor in particular are 'the luxury and caprice' of the rich. 'They consume little more than the poor; and in spite of their natural selfishness and rapacity, though they mean only their own conveniency, though the sole end which they propose from the labours of all the thousands whom they employ be the gratification of their own vain and insatiable desires, they divide with the poor the produce of all their improvements. They are *led by an invisible hand* to make nearly the same distribution of the necessaries of life which would have been made had the earth been divided into equal portions among all its inhabitants; and thus, *without intending it*, without knowing it, advance the interest of the society and afford means to the multiplication of the species. When Providence divided the earth among a few lordly masters, it neither forgot nor abandoned those who seemed to have been left out in the partition.' [11]

You will have been anticipating the passage I now go on to in the 'Wealth of Nations.' It is that in which he explains how it is that 'every individual,' by directing the domestic industry of a country 'in such a manner as its produce may be of the greatest value,' though 'he intends only his own gain,' 'is in this, as in *many other cases, led by an invisible hand* to promote an end which was no part of his *intention.*' * You observe how the very terms of the former treatise reappear; not only the 'invisible hand,' but also 'intention' and 'end'; and you will realise that 'in many other cases' is not a qualification he intends to be taken seriously. The 'invisible hand' is not, as some have supposed, the chance survival of a picturesque literary phrase; the idea, in that or some equivalent phrase, is the *leit-motif* of all his writing.

However the doctrine grew up in Smith's mind that—as one of my predecessors in this Chair has expressed it—'the *natural* forces of human desires and aversions . . . will *naturally*, and without conscious intention on the part of the individual, lead to the greatest advantage of society,' and however much he may have supposed himself to have reached it by observation of surrounding facts, there can be no doubt, as that predecessor of mine has pointed out, that it 'became the starting point' of 'the school of propagandists' who gave Political Economy its English connotation.[12]

So much the starting point that it was unconsciously assumed. It hardly occurred to most writers explicitly to set it forth; and here, as elsewhere, we can be grateful to McCulloch for proclaiming what others were thinking. 'The principles on which the production and accumulation of wealth depend are inherent in our nature' . . . and again: 'The principles which form the basis of this science make a part of the original constitution of man and of the physical world.' [13] And Buckle, summing up with

[10] Part IV., ch. i. (Reprint, p. 162.)
[11] *Ibid.* (Reprint, p. 163.)
* *W. of N.*, Bk. IV., ch. ii. (II. 28.)
[12] Sir H. Llewellyn Smith, at the Meeting of 1910.
[13] *Principles* (1825), p. 15. (Reprint, p. 16.)

unbounded admiration more than thirty years later the teachings of Smith, declares 'there is a provision in the nature of things by which the selfishness of the individual accelerates the progress of the community.'[14] Where the beneficence of natural liberty is not positively asserted, it is of course implied in the use of so condemnatory a term as 'artificial' to designate any limitation of it: as for instance in the Merchants' Petition drafted by Tooke in 1820.

It can be easily understood that when Political Economy passed into the hands of a stockbroker like Ricardo and of utilitarian agnostics like the two Mills, the language of theism would fall into disuse. No longer were they inclined to echo the old saying 'Nature: that is God Himself.'[15] And it was not only because they had ceased to think theologically: it was because some at any rate could hardly fail to be more or less conscious that the turn Ricardo had given to the doctrine had deprived it of its optimistic character, and made it uncomfortably fatalistic. 'Nature' was still enthroned; and if 'God' means only a Supreme Power there was no reason why Nature should not continue to be called God, or God's Vicegerent—were it not that that the Supreme Power which had established 'the Principle of Population' and 'the natural price of labour' could hardly be respected, let alone loved.

When, however, we get to the period of the Anti-Corn Law League there was a return to Smith's optimism and Smith's theism. 'The responsibility of having to find food for the people belongs,' says Cobden in 1846, 'to the law of Nature; as Burke says'—he continues—'it belongs to God alone to regulate the supply of the food of nations.'[16] It is congenial to him to appeal to 'the will of the Supreme Being'[17] and 'the moral government of the world';[18] and to describe Free Trade as 'the International Law of the Almighty.'[19] And with the return to a theistic conception went a return to the idea of natural rights, which the Benthamite economists had likewise thrown over. Thus the petition of the Manchester Chamber of Commerce, drawn up by Cobden and two of his friends in 1838, bases itself upon 'the unalienable right of every man freely to exchange the results of his labour for the productions of other people.'[20] The eloquent orator, W. J. Fox, refused on this ground to compromise on Free Trade: 'It is "the very stuff o' the conscience": it is a principle upon which we have made up our minds, as embracing the right of man anterior to the existence of civilised society.'[21] And after the further lapse of a quarter of a century, the editor of Bright's and Cobden's 'Speeches,' Thorold Rogers, becoming Professor at Oxford and writing 'A Manual for Schools and Colleges,' 'assumes,' as of course, 'that there are such rights as are called "natural," and that these are the inalienable conditions under which individuals take part in social life.'[22]

[14] *Civilisation in England*, vol. ii., ch. vi.
[15] The mediæval legist Azo 'explains Ulpian's *natura* by *id est ipse Deus*.' Pollock, *Essays*, p. 42, from Maitland.
[16] Speech of Feb. 27, 1846.
[17] Speech of Aug. 25, 1841, quoting a petition of ministers of religion.
[18] Speech of Oct. 19, 1843.
[19] According to Mallet, Intro. to *Political Writings of Cobden*, p. vi.
[20] Text in Hirst's collection, *Free Trade and the Manchester School* (1903), p. 142.
[21] Speaking in 1844, *Ibid.* p. 174.
[22] *Manual*, 2nd ed. revised, 1869, p. 223.

How far the return to Adam Smith's type of optimistic theism was due to the real religious sentiment of men like Cobden, to their own reading of the great Scotch master, and to the contemporary English environment, and how much it may have been due to the influence of the contemporary French writer Bastiat, it is not easy to say. Sir Louis Mallet, one of the literary custodians of Cobden's fame and associated with him in negotiating the French Treaty of 1860, regards it as 'one of those coincidences which sometimes exercise so powerful an influence on human affairs' that, while Cobden was leading a political movement in England, 'Frederic Bastiat was conceiving and maturing in France the system of political philosophy which still remains the best and most complete exposition of the views of which Cobden was the great representative.' 'These two men,' he affirms, 'were necessary to each other. Without Cobden, Bastiat would have lost the powerful stimulant of practical example. . . . Without Bastiat, Cobden's policy would not have been elaborated into a system.' [23]

Bastiat has had hard measure dealt to him by later writers. In exchange for the extravagant laudation he received at the time from politicians and popular writers, he has been treated by recent academic economists with a certain patronising contempt. It is allowed that his apologues or parables, like the Petition of the Candle Makers against the Sun, are amusing *reductiones ad absurdum* of some of the demands of the Protectionist man-in-the-street. But he is dismissed as 'a lucid writer, but not a profound thinker'; and the doctrine ascribed to him—'that the natural organisation of society under the influence of competition is the best not only that can be practically effected but even that can be theoretically conceived'—is characterised as 'extravagant.' [24]

I must avow that I have found nothing in Bastiat's most optimistic and theistic passages which is more than a more emotional repetition of Smith in the 'Moral Sentiments.' Smith tells us of 'that divine Being whose benevolence and wisdom have from all eternity contrived and conducted the immense machine of the universe, so as at all times to produce the greatest possible quantity of happiness.' [25] Bastiat uses the same mechanical image: 'The leading idea of this work, the harmony of interests, is religious. For it assures us that it is not only the celestial but also the social mechanism which reveals the wisdom of God and declares His glory.' [26] And the Divine Hand reappears: 'Since in the sphere of labour and exchange the principle "each for himself" must inevitably prevail as motive power, it is marvellous how the Author of things has made use of it to realise in society the fraternal motto "each for all." His skilful Hand [27] has made an instrument out of an obstacle. The general interest has been entrusted to private interest; and the former is inevitable precisely because the latter is indestructible.' [28] Before we of this generation are contemptuous of Bastiat, it is only just

[23] *Cobden's Political Writings* (1878), Intro., p. vi.

[24] Marshall, *Principles*, 4th ed., p. 64.

[25] *Moral Sentiments*, Pt. VI., Sec. II., ch. iii. (Reprint, p. 210.)

[26] Preface *To the Youth of France* to his *Harmonies Economiques* (1850). In English translation: *Harmonies of Political Economy* (1860), p. 9.

[27] 'Son habile main.'

[28] *Œuvres Choisies*, ed. Foville, p. 269.

to look into the rock whence he was hewn, and to the hole of the pit whence he was digged.

The truth is, Bastiat went behind Malthus and Ricardo, back to Adam Smith. He pointed out that what distinguished 'the Economist school' of his time from various Socialist schools was at bottom this: that the former believed and the latter did not in the necessary harmony of unrestricted individual interests. This harmony was the principle from which 'the Economist school' started in their arguments in favour of economic freedom. Their practical conclusions were in themselves correct; but the premise, the starting point, could not be correct, Bastiat averred—the harmony did not in reality exist—if the Malthusian doctrine of Population was true and the consequent Ricardian doctrine of Rent. And so, to save the premise, these doctrines must be thrown over.[29] And that, of course, is just what Cobden did, when he argued so frequently and strenuously against the fundamental proposition of Ricardo that the price of food regulates the rate of wages.[30]

Is it necessary to say that nowadays no serious thinker believes in the two propositions with which I have commenced? 'Natural' and 'artificial' are words we still use to beg a question; but no one is any longer at all thorough-going in their application. 'Nature,' as distinguished, as Adam Smith does, from 'the slow and uncertain determinations of our reason,' no longer has the comforting sound it once had. We may not think of Nature as 'Red in tooth and claw,' or say, with another great poet, 'Nature and man can never be fast friends'; but we can save Nature's character only by including in it precisely what Smith omitted: human reason. And when we put aside abstract prepossessions and simply watch the operation of social forces, we discover that on neither side of the antitheses, Freedom and Control, Liberty and Order, Competition and Combination, is there a necessary preponderance of good or evil. Factory Laws, Education Laws, Sanitation Laws alike show that no modern civilised State any longer believes that social interests can be left to the

[29] It is so easy to miss the precise point in a translation that it will be well to quote the original. 'J'ai dit que l'Ecole économiste, *partant de* la naturelle harmonie des intérêts, *concluait* à la Liberté. Cependant, je dois en convenir, si les économistes, en général, *concluent* à la Liberté, il n'est malheureusement pas aussi vrai que leur principes établissent solidement *le point de départ*: l'harmonie des intérêts.' And again: 'La *conclusion* des économistes est la liberté. Mais, pour que cette conclusion obtienne l'assentiment des intelligences et attire à elle les cœurs, il faut qu'elle soit solidement fondée sur cette *prémisse:* les intérêts, abandonnés à eux-mêmes, tendent à des combinaisons harmoniques, à la prépondérance progressive du bien général. Or, plusieurs d'entre eux, parmi ceux qui font autorité, ont émis des propositions qui, de conséquence en conséquence, conduisent logiquement au mal absolu, à l'injustice nécessaire, à l'inégalité fatale et progressive, au paupérisme inévitable.'

[30] It is interesting to pass from the first three paragraphs of Ricardo's ch. v. on Wages (1817) to Cobden's speeches of Feb. 24, 1842, and Feb. 8, 1844. Cobden avowedly bases himself in the matter of wages on Adam Smith; Speech of July 3, 1844. (*Speeches*, 1880, p. 105; cf. p. 119.) Compare the attitude toward Malthus and Ricardo of Cobden's friend, Thorold Rogers, who, in his *Manual*, speaks of Bastiat as 'the great French economist.' But before Bastiat there was at least one notable Free-trader who thought it necessary to protest against the Malthusian doctrine of Population and the Ricardian doctrine of Rent in order to preserve his exuberantly optimistic outlook. This was G. Poulett Scrope, the geologist and M.P., in his *Principles of Political Economy*, 1833. See Preface, p. viii., to edition of 1873.

unhampered working of immediate individual desires and impulses. It is arguable that 'Liberty' may still be the best policy to pursue in the matter of foreign trade. But the contention no longer starts with the immense presumption in its favour which it enjoyed so long as it was deemed the master key to a divine government of the world.

3, 4. The individualistic or 'atomistic' conception of society, or of the State as its organised expression, and the doctrine of the identity of individual and social interests (in the sense that the pursuit of individual interests must necessarily, in general, conduce to social interests) were, perhaps, not inevitably associated ideas. For society might be conceived of as a mere aggregation of individuals; and yet, within the society so formed, the pursuit of individual interests—since all individuals are not equally powerful—might conceivably be regarded as injurious to the majority, and, in that sense, to society itself. Some such view was inculcated by Hobbes. From such a conclusion Smith and his followers were saved by their underlying confidence in Nature. For if each individual retained or should retain in Society his natural rights, and if the final outcome was bound to be good, that could only be because the pursuit of individual rights resulted in the common advantage. It would be superfluous to point out that the individualist view of the essential nature of society, and of the State as its organised expression, led to the limitation of State functions and to the policy commonly known as *laissez-faire*.

As in the case of Natural Liberty we need not ask how the atomistic conception of the social union came to Adam Smith. That it characterises his school is very certain. But Smith was a man of wide reading, and knew too much to readily give himself away by generalities. It is interesting to see how his followers forced his ultimate principles into the open. A good example is furnished by McCulloch. Time has dealt hardly with McCulloch. His name has almost disappeared from modern treatises. But he was the man from whom the general British public mainly learnt its Political Economy between 1825 and 1850; and the republication of his first edition in cheap reprints secured currency for his teaching long after the middle of the century in certain circles, and that in its earliest and least qualified form. Peacock with his 'MacQuedy' in 1831, and Carlyle with his 'McCroudy' in 1850, knew well enough what they were about;[31] for McCulloch might reasonably be taken as 'the typical economist of the day.'[32]

McCulloch has been employed in setting forth the general argument for individual enterprise. As is his wont, he does not scruple to appropriate, without marks of quotation, choice sentences of Adam Smith—as, less frequently, of Ricardo.

Smith had written thus: 'Every individual is continually exerting himself to find out the most advantageous employment for whatever capital he can command. It is his own advantage, indeed, and not that of the society which he has in view. But the study of his own advantage naturally, or rather, necessarily, leads him to prefer that employment which is most advantageous to the society.'[33]

[31] In Peacock's *Crotchet Castle* and Carlyle's *Latter-Day Pamphlets.*

[32] Leslie Stephen, *The English Utilitarians*, ii., p. 226.

[33] *W. of N.*, Bk. IV., ch. ii. (Rogers' ed., ii. 26.)

Now listen how McCulloch copies this verbatim, but adds 'labour' to 'capital,' and emphasises the completeness of the social benefit. Notice still more how he, quite correctly, inserts into the middle of the argument the fundamental principle on which it rests: 'It may be observed that every individual is constantly exerting himself to find out the most advantageous methods of employing his capital and labour. It is true that it is his own advantage and not that of the society which he has in view; but, as a society is nothing more than an *aggregate collection of individuals*,[34] it is plain that each in steadily pursuing his own aggrandisement is following that precise line of conduct which is most for the public advantage.'[35]

The large assumption on which the conclusion depended, viz. that individuals know their own interest better than any other man, or 'select number of men,' can teach them is, with McCulloch, 'an admitted principle in the Science of Morals as well as of Political Economy'[*] which hardly calls for exposition.

An individualist view of the social bond involved, as I have already observed, a severe limitation of the functions of the State, or, in Adam Smith's language, of the 'sovereign.' Herein again Bastiat brings out what is implicit in Adam Smith. In his article on the State, written in 1848, in the midst of the Socialistic agitation of the period, he prides himself on being able thus to characterise it: 'The State is the great fiction by means of which everyone tries to live at the expense of everyone[36]. . .

'To-day as aforetime, everyone would like to profit by the toil of others. One doesn't dare to profess such a sentiment; one conceals it from oneself. So what does one do? We invent an intermediary; we turn to the *State*; and one class after another comes and says to it: "You, who can properly and honestly do so, take from the public; and we will share." Alas! the State has only too great an inclination to follow this diabolical counsel; for it is composed of ministers and officials—men, in fact, who, like all other men, desire at heart, and seize every opportunity, to increase their own riches and influence.'

For quite such sweeping language from an English pen we have to come to America. And here is a characteristic passage from that forcible little book by the late Professor Sumner of Yale, 'What Social Classes owe to Each Other':[37] 'As an abstraction, the State is to me only All-of-us. In practice—that is, when it exercises will or adopts a line of action—it is only a little group of men chosen in a very haphazard way by the majority of us . . . "The State," instead of offering resources of wisdom, right reason, and pure moral sense beyond what the average of us possess, generally offers much less of all these things'; and so on.

In the last half-century we have seen a high doctrine of the State entering into England, and in a lesser measure into America, as part of the influence of the Hegelian philosophy and of a renewed appreciation of the

[34] McCulloch's own italics.
[35] *Principles of Political Economy* (1825), Pt. V., ch. iv. (Reprint, p. 74.)
[*] Reprint, p. 16.
[36] '*L'Etat, c'est la grande fiction à travers laquelle* TOUT LE MONDE *s'efforce de vivre aux depens de* TOUT LE MONDE' (Bastiat's own capitals and italics).—*Œuvres Choisies*, ed. Foville, p. 94. There is a poor translation in a volume edited by D. A. Wells, *Bastiat, Essays in Political Economy* (1893).
[37] 1885, p. 9.

Greek view of the State. We have seen the High-State doctrine confirmed by the visible efficacy of much positive State action. We have seen it, more recently, somewhat discredited by its association in Germany with a deification of the State which has seemed immoral; and although the State in all countries undertook during the Great War, with quite unexpected success, novel functions, its activity has, for the time, undoubtedly left behind a certain soreness in some of the business interests affected. Moreover, there has been much analysis in recent years of the conceptions *Society* and *State*; much consideration of the place of groups or associations within the State, and of a conceivable partition of functions. There are schools of political thought who are so indignant with the use which Governments calling themselves 'the State' have made of their powers that they propose to abolish the State altogether: although their measures, when they seize power, indicate clearly enough that what they believe in is something similar under another name. For all these reasons, I naturally do not intend to set forth any view of my own, either as to Society or the State. I am content to have reminded you of the view entertained by the economists of the century we are considering. I do not suppose it would satisfy any serious thinker now. He might think Free Trade expedient; but he would not base it upon so one-sided and unhistorical a conception of the social union.

5. The idea that countries differ from one another in their physical productive resources, and that this is the occasion and justification of foreign trade, had been a commonplace with writers centuries before Adam Smith. It is to be found well developed in the letters of Seneca; it reappears in the great encyclopædic treatise of Aquinas;[38] and it was transmitted to the modern world by Grotius.[39] But there can hardly be any doubt that it came to Adam Smith from the well-known essays 'Of the Balance of Trade' and 'Of the Jealousy of Trade,' published by his friend David Hume in 1752 and 1758. Hume had written: 'Nature, by giving a diversity of geniuses, climates and soils to different nations, has secured their mutual intercourse and commerce so long as they all remain industrious and civilised.' And he had furnished Smith and his successors with a convenient shorter expression by remarking: 'When any commodity is denominated the staple of a kingdom, it is supposed' (*i.e.* understood) 'that this kingdom has some peculiar and *natural advantages*[40] for raising the commodity.'

Hume also led the way for Smith to draw the conclusion that interference with the international trade which would arise from the divergency in national advantages would be unwise. And it is an illustration of the

[38] This learning is not my own. References will be found in Kautz, *Geschichtliche Entwickelung der Nat. Oek.*, pp. 156, 215.

[39] Grotius (*De Jure Belli ac Pacis*, II., 2, 13, 5) quotes from the Greek rhetorician Libanius, of the fourth century after Christ, a passage which he translates thus: 'Deus non omnia omnibus terrae partibus concessit, sed per regiones dona sua distribuit, quo homines alii aliorum indigentes ope societatem colerent. Itaque mercaturam excitavit.'

[40] The expression had been used, in 1691, by John Locke, in his *Considerations of the Lowering of Interest* (Reprint in *Essays*: Ward, Lock & Co., p. 566). He says, of Commerce: 'For this the advantages of our situation, as well as the industry and application of our people . . . do naturally fit us. By this, . . . trade left almost to itself, and assisted only by tfie *natural advantages* above mentioned, brought us in plenty of riches.' But Locke was far from drawing the Free Trade conclusion.

hold which the current Nature philosophy had on men's minds that Hume, whose own theism was of the most tenuous and hesitating character, puts the conclusion in theistic language: 'These numberless bars, obstructions and imposts which all nations of Europe . . . have put upon trade . . . deprive neighbouring nations of that free communication and exchange which the Author of the world has intended by giving them soils, climates and geniuses so different from each other.'

It need hardly be said that this religious interpretation long continued to be usual. As the great financier Alexander Baring, later known as Lord Ashburton, declared, in presenting the Merchants' Petition to the House of Commons in 1820: 'It is one of the wise dispensations of Providence to give to different parts of the world different climates and different advantages, probably with the great moral purpose of bringing human beings together for the mutual relief of their wants.'[41]

'Natural advantages,' it will be allowed, will commonly be taken to mean advantages based on geographical conditions. This is what the reader, left to himself, would understand by Ricardo's language, when he says that 'a system of perfectly free commerce' uses most efficaciously 'the peculiar powers bestowed by nature'; [42] or by Cobden's language, thirty years later, when he speaks of England as setting 'the example of giving the whole world every advantage of clime and latitude and situation.'[43]

Smith is avowedly taking a strong case when he remarks that 'by means of glasses, hot-beds and hot walls very good grapes can be raised in Scotland, and very good wine too can be made of them—at about thirty times the expense at which they can be imported.'[44] But, if this is an extreme case, it is something equally clear in essential character, though usually less in degree, that the phrase 'natural advantages' is calculated to imply. And this is how Ricardo himself interprets it: 'It is this principle which determines that wine shall be made in France and Portugal, that corn shall be grown in America and Poland, and that hardware and other goods shall be manufactured in England.'[45]

It will be remembered that Ricardo was writing in 1817: it was then thought that English hardware rested upon natural blessings in the way of coal and iron which other nations did not possess. The 'natural advantages' which the United States and Germany, to mention no other countries, were destined to find in their coal and iron deposits had not yet been discovered. As late as 1832 McCulloch could write in his 'Dictionary of Commerce': 'The hardware manufacture is one of the most important

[41] Hansard (N.S.) I., p. 165, quoted in Page, *Commerce and Industry* (1919), I., 55.
[42] Chap. vii., on *Foreign Trade.*
[43] Speech of Feb. 27, 1846. A contemporary variant is 'varieties of climate, situation and soil,' in the *Edinburgh Review* for Jan. 1841 (a reference I owe to the late Professor Sidgwick). In Thorold Rogers we find a fresh spring of fervour derived from Cobden and Bastiat. The chapter on Foreign Trade in his *Manual* (1868) thus begins: 'The various regions of the earth are variously favourable to the growth of vegetable and animal products. Different countries too have different geological characteristics.' The exposition of 'special advantages' by the economist who replaced Rogers in the Oxford chair is on the same lines: Bonamy Price, *Practical Political Economy* (1878), p. 309.
[44] II., p. 31.
[45] *Principles*, p. 157.

carried on in Great Britain; and from the abundance of iron, tin and copper ores in this country, and our inexhaustible coal mines, it is one which seems to be established on a very secure foundation.'[46]

'Natural advantages,' however, as a basis for the universal application of the policy of free trade, was likely to suggest two comments. One is that the greater cheapness with which one country can produce goods as compared with another is obviously in some cases due to no peculiar advantage in the geographical sense, but simply to the historical fact that the manufacture was established there earlier. The other is that a country may even possess geographical advantages for a particular production but be unable to develop them if importation is free, because, for the time being, another country is producing more cheaply. If the 'intention' of 'the Author of the world,' or of 'Nature,' is shown by the provision of particular physical resources, it can hardly be supposed proper to allow it to be indefinitely 'counteracted';[47] and this vital point in the argument was seized upon by Alexander Hamilton. Hamilton, the author of the greater part of 'The Federalist,' is the most considerable name in the political science of the United States. His famous 'Report on Manufactures,' written in 1790, only fourteen years after the appearance of the 'Wealth of Nations,' and long before List and John Stuart Mill, shows a powerful mind working on the material presented to him by Adam Smith and the French economists, but with the needs and conditions of a new country before his eyes. And as soon as we realise that 'advantages' was a key-word in the discussion, we cannot but appreciate the dexterity with which Hamilton employs it to justify protection. Writing at a time when water was still the usual motive-power for the new machinery, he alleges that in that respect 'some superiority of advantages may be claimed' for the United States; as to the cost of materials, 'the advantage upon the whole is at present upon the side of the United States'; and, generally, 'it is certain that various objects in this country hold out advantages which are with difficulty to be equalled elsewhere.'[48]

Adam Smith was quite shrewd enough to foresee criticism on this line. He meets it boldly: 'Whether the advantages which one country has over another be natural or acquired is in this respect' (*i.e.* cheapness) 'of no consequence. So long as the one country has these advantages and the other wants them, it will always be more advantageous to the latter rather to buy of the former than to make.'[49] This is of course perfectly true, but inconclusive. That one policy is clearly more advantageous in the short run does not prove that it must be more advantageous in the long run.

[46] J. L. Mallet in his *Diaries* (excerpted in *Political Economy Club, Centenary Volume*, 1921) comments on the success of this Dictionary: 'Two thousand copies of the first edition sold, at 2*l*. 10*s*. a copy, in the course of nine months.' Cobden, in 1835, described it as 'a work of unrivalled usefulness, which ought to have a place in the library of every merchant and reader who feels interested in the commerce of the world.'

[47] In the case of the exchange of English cloth for Portuguese wine, 'the intention of Nature' was indicated to McCulloch by, *inter alia*, 'the superiority of the wool of England, our command of coals.' etc. (Reprint, p. 71.)

[48] In the reprint in Taussig's collection: *State Papers and Speeches on the Tariff* (Cambridge, Mass., 1893), pp. 35, 36, 39, and elsewhere.

[49] Bk. IV., ch. ii. (II., p. 31.)

The form of the long-run idea with which we are most familiar in England is the concession which Mill makes, as he says,' on mere principles of political economy,' with respect to the possible wisdom of imposing protective duties 'in hopes of naturalising a foreign industry in itself perfectly suitable to the circumstances of the country,' *i.e.*, as he goes on to say, 'where there is no inherent disadvantage.'[50] This, the so-called 'Infant Industries' argument, I need not further elaborate. Mill recognises that such a policy involves a burden so long as the new industry cannot stand without protection; but 'a protecting duty will sometimes be the least inconvenient mode in which the nation can tax itself for the support of such an experiment.' It may be remarked that Mill's statement of the economic and psychological difficulties under which a new industry, in itself perfectly suited to a country, will ordinarily labour, is nothing more than what Hamilton had said fifty-eight years before.[51] Neither of them mentions a consideration which modern business has made of vast importance: the greater economy of manufacture which large-scale production enjoys owing to the wider distribution of overhead charges.

The form in which the same idea was presented to the German public by List was of more philosophical generality. It is summed up in the contrast between a policy based on present 'exchange values'—which is his not unjust way of paraphrasing the language of Adam Smith—and a policy based on 'productive powers.' By suffering a present loss, a country may secure for itself a permanent source of wealth, which may repay, many times over, the initial loss.

I do not propose to enter into the tangled and highly controversial question of the extent to which the policy of protecting infant industries or developing productive powers has been or can be wisely applied in particular countries, at different stages of development, and with varying physical resources. I do not forget what is said, and said with a good deal of obvious justice, about the selfishness of particular interests, and about infants not growing up. It is not necessary to substitute for the belief in the necessary beneficence of human selfishness under free trade any belief in the necessary beneficence of human selfishness under protection. But it is fair, I think, to say that experience, since the time of List and Mill, is not altogether barren of what may reasonably be regarded as successful applications of the List and Mill principle. As my purpose is merely to examine the free trade doctrine of Adam Smith and of the century following as a piece of abstract argument, I will take only one case.

The tariff history of the United States has long been the happy hunting-ground for those who sought evidence of the sordidness of protectionist politics. The conjunction of the development of vast physical resources with the working, for the first time on a big scale, of practical democracy, created conditions not always favourable to political virtue. 'Lobbying' has become a term of such evil sound that to some minds it makes further argument unnecessary.

If, in this sea of dubious issues, any writer can be supposed to steer a judicious course, I suppose it is Professor Taussig, the colleague by whose side I was proud to serve many years ago at Harvard. In successive

[50] Bk. V., ch. x., p. 1.

[51] See the 'very cogent reasons' set forth by Hamilton, p. 29, *seq.*

editions of his book since 1882, he has earned our gratitude by putting before us, if not all, at any rate most of, the main facts of United States tariff history. Moreover, he has been one of the few writers who have illustrated from modern experience the Ricardian doctrine of comparative costs, the more subtle form of the general doctrine of natural advantages. And now let us listen to what he has had recently to say of the iron industry of the United States during the forty years preceding 1915.[52] I am anxious not to involve him an inch beyond the distance he would be willing to travel. I will therefore quote a sufficiently long passage, and will add that, to do him complete justice, it should be read *in situ*.

'It might be alleged that the iron industry would have advanced during the forty years in much the same way, protection or no protection. And yet the unbiassed enquirer must hesitate before committing himself to such an unqualified statement. Rich natural resources, business skill, improvements in transportation, widespread training in applied science, abundant and manageable labour supply—these, perhaps, suffice to account for the phenomena. But would these forces have turned *in this direction* so strongly and unerringly but for the shelter from foreign competition? Beyond question, the protective system caused high profits to be reaped and the stimulus from great gains promoted the unhesitating investment of capital on a large scale. . . . Thereafter, the community began to get its dividend. Prices fell. . . . The same sort of growth would doubtless have taken place eventually, tariff or no tariff; but not so soon, or on so great a scale.

'No one can say, with certainty, what would have been; and the bias of the individual observer will have an effect on his estimate of probabilities. The free trader . . . will be slow to admit that there are any kernels of truth under all this chaff . . . On the other hand, the firm protectionist will find, in the history of the iron trade, conclusive proof of brilliant success. And very possibly those economists who, *being in principle neither protectionists nor free traders*, seek to be guided only by the outcome in the ascertained facts of concrete industry, would render a verdict here not unfavourable to the policy of fostering "national industry."'

The fact that such a verdict is possible in an outstanding case of this magnitude is not likely to impede the remarkable inversion of the old 'natural advantages' argument which we can see taking place nowadays in several directions. There has, of late, been an increase in the number of States which have independent control over their fiscal policy. The belief—which may or may not be well founded—that these countries are fortunate in their climates, or soils, or mineral resources, or water-power, or any other of the physical gifts of their geographical situation—and these are what the ordinary man means by 'advantages'—is now suggesting to them that, as with any other estate, it may pay them to expend something on development. Tariffs or bounties are, of course, from this point of view, simply forms of development expenditure. They would be inclined to echo the words of Adam Smith, though with a different application: 'What is prudence in the conduct of every private family, can scarce be folly in that of a great kingdom.'[53]

[52] *Some Aspects of the Tariff Question* (1915), p. 150.
[53] Bk. IV., ch. ii. (II., p. 29.)

An obvious case in point is India, in its new constitutional character. In 1922 the Indian Fiscal Commission, after pronouncing for a policy of protection 'with discrimination,' recommended the appointment of a Tariff Board to exercise that discrimination, and laid down the principles by which it was to be guided. And the very first is: 'The industry must be one possessing natural advantages, such as an abundant supply of raw material, cheap power, a sufficient supply of labour, or a large home market.'

In this present year the Indian Tariff Board has made its first report on a specific industry. It recommends protection for the Indian steel industry on these grounds: 'India possesses great natural advantages for the manufacture of steel, owing to the richness and abundance of the iron-ore deposits and the comparatively short distance which separates them from the coal-fields. The natural advantages are so great that eventually steel manufacture in India should be possible at as low a cost as in any other country.' Perhaps I had better say that I have no opinion on the particular proposal myself. I do not know whether the rich and abundant iron-ore deposits do in fact exist. But if they do, they are what the ordinary man means by 'natural advantages.'

To the Smithian economist, need I say, the only proof that a country has an 'advantage' is the fact that it can produce more cheaply? 'Advantage' with him is a comparative not a positive idea. And yet it carries with it an implication that does not necessarily belong to it. In this respect it is like the biological conception of the 'fittest' to survive, or, to come nearer home, the economist's employment of 'utility.' 'Advantage' suggests that its possession is necessarily a good thing for the country which has it. But, in the comparative sense, every country which has a foreign trade at all must have an 'advantage' of some kind or other, or it would not be able to export. Anything which enables it to produce exports more cheaply than it is worth while for the importing country to produce them is an 'advantage.' Read Professor Taussig's books: you again and again come on the idea that the reason why the United States should not enter upon this or the other branch of production is that the commodities in question—*e.g.* beet sugar—are more cheaply produced abroad by docile, unintelligent labour: 'an inferior class which is utilised, perhaps exploited, by a superior.' He comes as near contempt for them as is possible for a humane man. But if, in the interchange of American machinery for European sugar, America's advantage is in its high-grade labour, by parity of reasoning the economic advantage of Europe is in its low-grade labour. And while this may be a reason for satisfaction on America's part, it is not so evidently a reason for satisfaction on Europe's part.

And, indeed, as soon as we begin to take a large view of history, it is quite certain that the utilisation of comparative advantages has sometimes been either a curse or a very mixed blessing. We are all familiar with Polish corn as supplying something like a local habitation and a name to the argument as to comparative costs. [54] But there is reason to believe that the export of corn from the Baltic lands to the countries of Western Europe was one of the causes for the depressed position of the peasant of

[54] See *e.g.* James Mill, *Elements* (1821), pp. 84-88, 135-137; followed by J. S. Mill, *Principles*, Bk. III., ch. xvii., § 2.

the Baltic lands in the 17th and 18th centuries.[55] And in the 19th century, when the Prussian *Junker* was a strong free trader in order to get a foreign market for his corn, he consolidated the economic 'advantages' of the lands east of the Elbe by buying up peasants' holdings and creating an agricultural labourer class which has become the most unsatisfactory feature in the German agricultural position.[56] Similarly, I suppose we all feel that the expansion of the American cotton area, and with it of slavery—during a period when the Southern planters were ardent free traders and anxious that England should be free to buy their raw cotton with its manufactures,[57]—was a means of elevating the coloured race which it is difficult to look back upon with equanimity.

6. The next idea with which we have to deal is that every country has a particular supply of capital and labour, and that the State can do nothing, by protective measures, beyond diverting them to what is presumably a less profitable employment. This is stated by Adam Smith, first generally: when he says that a monopoly of the home market frequently turns towards a particular employment 'a greater share of both labour and stock of the society than would otherwise have gone to it'; and then when he makes everything depend on capital, and says that 'no regulation of commerce can increase the quantity of industry beyond what its capital can maintain: it can only divert a part of it.'[58] 'Diversion' is the key-word.[59]

I will follow Smith's example by concentrating first on capital. And as soon as one looks into the exposition as found in Smith or McCulloch or John Stuart Mill, it must be apparent that the idea has a close resemblance to another once dominant[60] which Mill himself publicly abandoned in 1869, and which few English-writing economists have since had the temerity to say a good word for: the so called Wage-fund Doctrine. In formulating the 'diversion' argument Smith uses language about wages of which the doctrine of the Wage Fund, as defined later, was merely a crystallisation: 'As the number of workmen that can be kept in employment by any particular person must bear a certain proportion to his capital, so the number of those that can be continually employed by all the members of a great

[55] See the interesting account in Naudé, *Getreidehandelspolitik*, I., 385 (in the series *Acta Borussica*: *Denkmäler der Preussischen Staatsverwaltung*, 1896). Naudé attributes the social condition of Poland, the cause of most of its political troubles, to the fact that its Government was not allowed by the landlords in the eighteenth century to pursue a mercantilist policy.

[56] See *Memorandum V.* on *Germany*, by the present writer, in *Final Report* of the Agricultural Tribunal of Investigation (1924), especially §§ 3, 4, 10.

[57] The English reader to whom the connection between slavery and the free trade views of the Southern States may be unfamiliar will find some of the relevant facts in Dewey, *Financial History of the United States* (1903), § 80; Bogart, *Economic History of the United States* (1907), § 217; Coman, *Industrial History of the United States* (1905), p. 190.

[58] II., pp. 25-26; cf. p. 272. Cf. J. S. Mill, *Principles*, I., v., § 1; Rogers, *Manual*, p. 235.

[59] The phraseology was probably suggested by Hume, who, expounding an idea considered below, says, 'If the spirit of industry be preserved, it may easily be diverted' (Essay *Of the Jealousy of Trade*).

[60] How dominant we are inclined to forget. But we may be reminded of it by reference to the once famous work of Buckle, *History of Civilisation* (1857), Vol. II., ch. vi., p. 357. Buckle speaks of it as 'this vast step in our knowledge.'

society must bear a certain proportion to the whole capital of that society, and never can exceed that proportion.' [61]

What Mill said about the Wage Fund is equally applicable to 'the capital of a society' in its relation to industry: it is 'not regarded as unalterable, for it is augmented by saving and increases with the progress of wealth; but it is reasoned upon as at any given moment a predetermined amount.' [62] By a writer like McCulloch, who delights to make things superabundantly clear, this is expressly stated: 'No country can possibly employ a greater number of workmen than its capital can feed and maintain. But it is plain that no restrictive regulation can of itself add one single atom to the capital.' [63]

The reason, of course, is that given by Adam Smith: 'The industry of the society can augment only in proportion as its capital augments, and its capital can augment only in proportion to what can be gradually saved out of its revenue.' [64]

But all this rests upon a view as to the character and extent of the fluidity of capital which was current among the writers of the period we are considering but which subsequent experience has shown to require profound modification. It was a view which, as we now see, combined an exaggerated estimate of the extent to which already invested capital is transferable within a country with a quite insufficient estimate of the extent to which newly accumulated capital is transferable as between one country and another.

As to the export of capital, Ricardo struck the note in 1817: 'Experience shows that the fancied or real insecurity of capital, when not under the immediate control of its owner, together with the natural disinclination which every man has to quit the country of his birth and connections, and intrust himself, with all his habits fixed, to a strange Government and new laws, check the migration of capital. These feelings, which I should be sorry to see weakened, induce most men of property to be satisfied with a low rate of profits in their own country, rather than seek a more advantageous employment for their wealth in foreign nations.' [65]

All these human touches—'fixed habits,' and so on—are more appropriate to the age before joint-stock companies than to ours. Ricardo's account of the situation is so moderately expressed that it may be defended, even for our time, by a charitable interpretation. But the conclusion drawn by the succeeding generation was in fact a pretty sweeping one. To this clear testimony is borne by that Ricardian of Ricardians, Professor Cairnes, writing in 1874: 'The assumption commonly made in treatises of Political Economy is that, as between occupations and localities within the same country, the freedom of movement for capital and labour is perfect, while, as between nations, capital and labour move with difficulty or not at all.' [66]

[61] II., p. 26.

[62] *Dissertations and Discussions*, IV., p. 42, *seq.*, excerpted in my edition of Mill, p. 992.

[63] Reprint, p. 73.

[64] Bk. IV., ch. ii. (I. 30.)

[65] *Principles*, ch. vi., p. 161.

[66] *Some Leading Principles of Political Economy Newly Expounded* (1874), p. 302.

Alexander Hamilton as early as 1790 showed a more statesmanlike prevision of the future trend of affairs: 'Notwithstanding there are weighty inducements to prefer the employment of capital at home, even at less profit . . . yet these inducements are overruled either by a deficiency of employment or by a very material difference in profit. . . . The aid of foreign capital may safely and with considerable latitude be taken into calculation'[67] by a country in the then position of the United States.

The history of Foreign Investment and its relation to Production is so far an almost untrodden field for the economic enquirer. Some sort of impression of the magnitude of the forces set at work may be given by the calculation that, before the war, British investments in other lands amounted to some 3,500 millions of pounds sterling, almost one-fourth of the total wealth of the United Kingdom,[68] or by the 'common belief in the City (of London) prior to the war that the annual savings of the United Kingdom were than about 400*l.* millions, and were devoted half to foreign and half to home investment.'[69]

No one, I hope, will jump to the conclusion that what I am maintaining or even desirous of suggesting is that investment in other countries is necessarily injurious to the industry of the country wherein the capital has been created. I must not be supposed to be unaware of the contention that British investments abroad may help to provide Britain more cheaply with food or materials, or in other ways make foreign lands better customers for English goods. All I desire to make clear is that the proposition that all a Government can do by its legislation is to affect the application within the country of a predetermined quantum of capital is not tenable. It can indubitably, in some measure, influence, whether wisely or not, the quantum either of home-created or of foreign capital, or of both, devoted to production in a particular country.

In cases where there is no hint of protection by means of tariffs or subsidies to suggest alarm, this fact that Government can affect the quantity of capital employed is generally recognised. Thus, the desirability of encouraging an influx of foreign capital to England was one of the avowed motives of the Patent Act of 1907. Four years later it was asserted, apparently on official authority, that 'some fifty firms had commenced, or were about to commence, work under the Act, and that the new factories involved a total outlay of some 800,000*l.* It was hoped that employment would, in this connection, be found for 7,000 additional men, and that the wages paid to them would total something like 8,000*l.* per week.'[70] It may well be that these estimates were over-sanguine; but it does not seem to have occurred to anyone to deny that some attraction of foreign capital to England might reasonably be expected to take place, and that, so far as it did occur, it would be beneficial to England.

[67] *Report*, pp. 38, 39.

[68] This results from a comparison of Sir George Paish's calculation of 'Great Britain's Capital Investments,' in *Jour. Roy. Stat. Soc.*, LXXIV., p. 187 (1911), with the *Economist's* calculation of national wealth in Hirst's chapter added to Porter's *Progress of the Nations* (1912).

[69] Lavington, *The English Capital Market* (1921), p. 205.

[70] *Times*, March 23, 1911.

And one may go a step further. That, under certain circumstances, a tariff might have the effect of causing foreign manufacturers to set up works within the tariff walls has, for some time past, been illustrated by numerous and not unimportant examples; and English manufacturers have not been deterred from yielding to the pressure of foreign tariffs and establishing works abroad by any personal views of their own as to Free Trade or Protection.[71] They have often taken with them a nucleus of skilled English workmen.

But now, in recent years, various Governments have begun once more to take notice of the fact that tariffs do, under certain circumstances, cause foreign capital to be introduced, and to use it as part of the justification of a protective policy. I may give two examples. One can get from the Bureau of Commerce and Industry of the Commonwealth of Australia a long list of 'some of the British Manufacturers who have established interests in Works and Factories in Australia.' Among them will be found a dozen or more of the best-known English concerns. And the list is headed by the following notes:—

'(1) New names are being added to this list every week, and it shows that in the opinion of some of the most progressive British manufacturers it will pay to bring plant and skilled workers to the raw material in Australia . . .

'(2) The new Australian Tariff is calculated to bring about the establishment of every natural and essential industry; and as the tariff affords real protection and opens up excellent prospects to the efficient, the next few years will see considerable industrial progress in Australia.'

I have no opinion as to the wisdom, in Australian interests, of its present tariff. I cite the case simply as showing how impossible it is now to speak as if the capital which a country can have for its manufactures must always be entirely accumulated within the country itself.[72]

The other case is even more significant. The new Irish Free State appointed last year a Committee of five Irishmen, of whom four were economists, to advise it as to its tariff policy. The Committee reported in what, with sufficient accuracy, may be called a free trade direction. But in that report occurred the following passage: 'The more complete the protection afforded by a tariff, the greater will be the inducement to outside competitors to retain their Irish market by coming inside the fiscal barrier and establishing factories in the Free State. And in the existing condition of industry the expenditure will be undertaken by very large industries in the hope of retaining even a small fraction of their existing market. . . . The new competitor will, it is true, in a sense establish an Irish industry and provide employment for Irish workers.'

All that the Committee find to say, by way of demurrer, is that 'in this case backward Irish industries will be faced by a home competition from a highly organised rival quite as serious as that from which they have sought to escape.'[73] That is to say, free trade must be maintained in the interests of 'backward Irish industries.'

[71] Some examples prior to 1903 are collected in my *Tariff Problem*, p. 77.

[72] This was Sir Robert Giffen's line of thought as recently as 1877. In his paper on Foreign Competition he argues that 'the amount of capital required to replace us even partially is so great that it must take many years *for our competitors to accumulate* any such amount' (*Economic Inquiries and Studies*, II., p. 429).

[73] *Reports of the Fiscal Inquiry Committee*, Dublin, 1923, § 126.

A century and a third before, Alexander Hamilton had thought it necessary to refer to a like fear of competition with the home producer: 'It is not impossible that there may be persons disposed to look with a jealous eye on the introduction of foreign capital, as if it were an instrument to deprive our own citizens of the profits of our own industry.' His own view was different: 'Instead of being viewed as a rival, it ought to be considered as a most valuable auxiliary; conducing to put in motion a greater quantity of productive labour and a greater portion of human enterprise than could exist without it.' [74]

The Government of the Irish Free State seems more inclined to follow Hamilton's lead than to be deterred by the prophecy of its Tariff Commission; for the Minister in charge of the measure which has lately been introduced into the Dail for 'a limited . . . experiment in the use of a tariff for the stimulation of Irish industry' [75] expressly mentioned the expectation of attracting capital from outside as one of the motives justifying the new departure. Here, again, I had better safeguard myself: as to whether a tariff on the particular commodities proposed is wise for Ireland I am not in a position to have an opinion; nor do I know how much non-Irish capital is likely to be attracted in these particular cases. I refer to this instance of Ireland simply as showing that not only the Irish Government but also its Committee of Economists are of opinion that legislation can have some influence on the amount of capital employed within the country.

I shall pass to more controversial ground if I refer to recent events in Great Britain itself. But it ought to be possible to state what, as far as one can make out, are assured facts without implying necessarily any opinion as to the policy with which they are associated. One is that the Swiss Chemical interests have been encouraged to enlarge considerably their plant in England since the Dyestuffs (Import Regulation) Act became operative in January 1921. The other is that the McKenna Duties have led some of the largest foreign manufacturers of motor-cars to establish works in Great Britain. They have usually begun with the importation of parts, and with merely assembling and finishing in Great Britain; yet even for that purpose large factories and many workpeople are necessary. In one important instance, manufacture has become almost entirely British. That the British preference on imports from the Dominions has had the effect of causing a certain transfer of American capital to this Dominion is, of course, well known to the Canadians in my audience.[76]

Perhaps some countries may be the better without imported capital and others without exporting it: perhaps the Governmental measures which influence the movement in either direction are ill-advised, and we

[74] *Report on Manufactures*, p. 39.

[75] Dail Eireann: *Parliamentary Debates*, April 25, 1924, p. 42 (tobacco, boots, confectionery); 70 (jam), cf. the utterances of other Deputies; 127 (boots); 130 (tobacco); 155 (soap).

[76] As lately as 1887 Lord Farrar will be found arguing that the increase in wages paid and persons employed in Canada under its protective policy must have been due to 'a compulsory and artificial transfer of the labour and capital *of Canadians* from the industries in which they can produce more, to,' etc.: *Fair Trade v. Free Trade* (4th ed., 1887, p. 63). The investment of foreign capital, especially American, in Canada, awaits, I think, its historian.

may sigh for the uncomplicated simplicity of the time when every country used only, and used all of, the capital it had itself accumulated. But that is not the world in which we live.

7, 8. The next of the generally accepted propositions in the sequence we are now considering was this: that while the capital and labour within a country were quantities the amount of which no Government action could influence, they could readily be transferred from one industry to another within a country, if their previous employment were taken from them by imports. It is the doctrine of the Internal Transferability of capital and labour, as existing conditions rendering free trade always beneficial.

The history of the literary presentation of the idea is suggestive. Like so much else, it probably came to Smith from Hume. Hume, in seeking to remove the alarm lest the 'interference' of our neighbours with any of our staple trades could do us great harm, argues that 'if the spirit of industry be preserved, it may *easily* be diverted from one branch to another; and the manufacturers of *wool*, for instance, be employed in linen, silk, *iron*, or any other commodities for which there appears to be a demand.'[77]

From this statement Hume would probably not have been disposed to draw the sweeping practical conclusions of later writers;[78] yet here is the transferability idea in germ. Of the idea in relation to capital I have already said something. Let us fix our attention on labour; for 'manufacturers' here means manual operatives.

Hume was writing in 1758. The use of coke for smelting iron was only just beginning; none of the great inventions in the iron and mining industries had yet been introduced: neither puddling, nor rolling, nor the steam engine. The only textile industry to which 'power' had been applied was the relatively small silk industry; not one of the revolutionary changes in cotton spinning and weaving had been made, and the engineering and shipbuilding trades were far in the future. Moreover, Hume is specifically referring to 'the staple industries' of the country; and there may have been some justification in the pre-machine age for thinking that—except in the case of highly skilled artisan crafts producing luxury goods—labour could move pretty easily to and fro. Even so, the 'easy' diversion of workpeople from the textile industries to the iron manufacture rather suggests a literary man's unacquaintance with the actual conditions of working-class life.

Adam Smith, twenty years later, thought it necessary to argue the matter more at length. He makes four points.[79] The first is, that the soldiers and seamen disbanded at the end of the Seven Years' War were gradually absorbed in the great mass of the people and found work in a variety of ways, without any 'sensible disorder,' 'though they no doubt suffered *some inconveniency*.' 'To turn the direction of industry from one sort of labour to another' 'is surely much easier.' The second is that, 'to *the greater part of manufactures* there are other *collateral* manufactures of so similar a nature that a workman can *easily* transfer his industry from one of them to another.' The third is that '*the greater part of such workmen*

[77] Essay, *Of the Jealousy of Trade*. (Reprint, p. 197.)

[78] For he continued to print by the side of this Essay the preceding Essay in which he argued that 'a Government has great reason to preserve with care its people and its manufactures.'

[79] Bk. IV., ch. ii. (II. 43); italics added.

are occasionally employed in country labour.' And finally that, whatever happens, there will, in any case, remain the same 'stock' or capital in the country, and that this will employ an equal number of people in some other way.

Obvious comments may be made on each of these points. The use of a term like 'inconveniency';[80] the use of the word 'easily' to describe transference even to 'collateral' manufactures;[81] the view that whatever particular home industry might be killed by foreign imports, 'the capital of the country remains the same'—a view so increasingly difficult to hold, as capital comes to be fixed in specialised plant; these points each suggest some evident reflections.[82] But it will be enough to dwell for a moment on the remarkable argument that 'the greater part of workmen in manufactures are occasionally employed in country labour.' In the age of 'domestic industry,' agriculture and manufacture were in truth often combined, in various ways, by the same persons or families; though one may doubt whether this was true of 'the greater part of workmen in manufactures' in England at the time Smith was writing. Need one say that the whole trend of development ever since has been away from such a combination, above all in England?

When we come to McCulloch, half a century later, there is an unmistakable change in the intellectual atmosphere. This country had in the interval entered, first of all the nations, into the machine and factory age; and, whether it was owing to that cause alone and the consequent cheapness of our commodities, or to other causes also, England had for the time a monopoly of the most important manufactures. The cotton industry, hardly existent in 1776, in 1825 was exporting goods to the value of much over 18 millions of pounds sterling. We had been, on balance, an iron-importing country; in the last three decades, imports had fallen by three-quarters, and exports had quadrupled. Accordingly, McCulloch could write quite in the strain of *Rule, Britannia!* Other nations might not be so blest, but *we* should flourish! Whatever 'loss and inconvenience' might follow a Free Trade policy 'in other countries,' 'our superiority in the arts is so very great, that only a very inconsiderable proportion of our population would be driven from the employments now exercised by them by the freest importation of foreign products.'[83]

Accordingly there was no need to alleviate possible apprehension by invoking the aid of occasional agricultural employment. Any residue of

[80] The word is echoed by Fawcett, *Free Trade and Protection*, p. 9: 'The loss and inconvenience which always accompany the transfer of capital and labour from one employment to another.'

[81] Smith did, at any rate, unlike Hume, limit the ease of transference to 'collateral' manufactures. T. B. Say—who, according to Ricardo, 'succeeded in placing the science' of Smith 'in a more logical and instructive order,' and had more influence on English writers than is now remembered—rivals Hume in his economic imagination. If, he says, France refuses to take English woollens, 'England will employ the same capital and the same manual labour in the preparation of ardent spirits by the distillation of grain that were before occupied in the manufacture of woollens for the French market.' (1803; English translation of 1820.)

[82] Smith on the next page recognises that that part of manufacturing capital 'which is fixed in workhouses and in the instruments of trade could scarce be disposed of without considerable loss.' He could not foresee how large a part this was destined to become.

[83] Part II., Section II. (Reprint, p. 76.)

doubt could be expeditiously disposed of by a piece of abstract argument, showing that, even in the improbable contingency that 'a few thousand workmen' lost their jobs through free imports, no harm would be done. For since imports must be paid for by exports, an amount of work *must* be called for to create them, 'equivalent' to that dispensed with. And this doctrine is asserted in its starkest form. There is no suggestion that the gain will be to the men already in those *other* trades which will now have larger exports, so that the nation would not suffer *as a whole*; or that the labourers now left idle will *ultimately* get absorbed. No; nobody is going to suffer, even for a short time. 'Suppose that, under a system of free trade, we imported a considerable portion of silks and linens now wholly manufactured at home . . . It is obvious that *such* of our *artificers as had* previously *been engaged in our silk and linen manufactures,* and were thrown out of these employments, could *immediately* obtain employment in the manufacture of the products which must be exported as equivalents for the foreign silks and linens.' [84]

It was not for another half-century that an English economist who could get the ear of the public began seriously to consider how far the transferability of labour and the transferability of capital—which he justly described as 'the postulates of' the then current 'Political Economy'—were in fact true.[85] Anyone who looks at his *Economic Studies* [86] will observe that Bagehot gives much more attention to capital than to labour; and that, as to labour, he occupies most of his space in demonstrating that in earlier times and to-day in primitive countries labour is *not* transferable. But, for such a country as England is now, he thinks 'no assumption can be better founded.' Labour does not flow so quickly from pursuit to pursuit as capital does: 'but still it moves very quickly.' There are, he grants, even at present in England, many limitations to mobility. 'There is a "friction," but still it is only a "friction"; its resisting power is mostly defeated, and at a first view need not be regarded.'

Like so much else in actual industrial life the question of the extent of the mobility of labour has been subjected to very little quantitative investigation. But all who have come into close contact with the industrial population of the older countries will agree with me in feeling that 'friction'

[84] In the edition of 1843 (p. 151) for *immediately* is substituted *in future*. But it is still the discharged artificers themselves who find the equivalent occupation.

[85] Senior, as long before as 1835, had pointed out, with remarkable insight, that the mobility of labour was being lessened rather than increased by the industrial revolution. 'The difficulty with which labour is transferred from one occupation to another is the principal evil of a high state of civilisation. It exists in proportion to the division of labour.' As to capital, he anticipated recent writers by pointing out that 'those costly instruments which form the principal part of fixed capital can scarcely ever be applied to any but their original purposes. They are employed, therefore, in the same way, long after they have ceased to afford average profit on the expense of their construction, because a still greater loss would be incurred by attempting to use them in a different manner.'—*Political Economy* (in the series *Encyclopædia Metropolitana*), reprint of 1854, p. 217.

The disregard by subsequent writers of what one might suppose suggestive observations is curious when contrasted with the readiness with which Senior's Abstinence view of Interest and his sharpening of the Wage Fund idea were accepted. It was, perhaps, due to the failure of Senior to make any large theoretic use of the observations. And ideas which can be fitted into a prevalent general body of thought are more likely to be assimilated than disturbing ones.

[86] 1880, p. 21, *seq*.

is an inadequate and misleading term, and that, in any case, it is very necessary to go on to a 'second view.' Doubtless there is a considerable slow-movement mobility—the mobility of a glacier rather than that of a stream. It is chiefly exhibited in the inclination of young people (or their parents) away from obviously declining trades and towards such trades as happen to be within their reach where employment is supposed to be good. And then there are occupations—for instance, that of a carpenter—in which men can find employment in two or more alternative 'industries,' in the wider sense of that word now coming into use—for instance, in building proper or in shipbuilding. But the fact seems also to be that a workman with definite acquired skill seldom changes his occupation in a country like England; and I imagine this is the case also in the older countries of Europe. Even unskilled men, mere 'labourers,' seldom leave 'the industry'—in the wide sense of the term—with which they have been associated. This is the case even when better-paid and more regular work is in fact available in some other occupation: the reasons are to be found partly in inertia, partly in attachment to local ties, but also quite as much in the need, or supposed need, of acquiring new skill, and the difficulty as well as risk of doing so. And hence, when men become unemployed, they cling to their own trade in the hope of being taken on again, to an extent which is inconceivable to middle-class people. Still more is this the case when it is short time or lowered remuneration they are suffering from.

Some of the recent developments of industrial organisation and legislation in the older countries which most of us regard with satisfaction have for their effect to lessen mobility. This is the result, for instance, of trade unionism, among more or less skilled operatives. The assertion that 'trade unions increase mobility of labour' [87] is true as between particular shops and particular localities in the same industry: it is the reverse of true for adult workpeople who desire to shift from one industry to another. To say that certain trade unions do in effect impose obstacles to entry upon a trade is not necessarily to condemn them: it is but to state a fact. Unemployment insurance again, in a country where there are recognised standards of wages, is bound, if it recognises a claim to a certain standard on the part of unemployed persons, to strengthen the tendency of workpeople once in a particular trade to stick to it. The National Insurance Act of 1920 lays down that a workman is justified in demanding unemployment benefit and declining proffered employment if that employment is not 'suitable.' If employment is offered in the same district—as will often be the case—it can be refused if the rate of wages is lower or the conditions less favourable than in the employment in which the workman was before ordinarily employed. And there seems to be a natural tendency in recent decisions of the courts to allow specially trained or skilled men and women to refuse unskilled work, especially if it could be thought to endanger their return to skilled employment.

The effect which unemployment insurance may well have in this respect is more than hinted at in the comments of several of the Governments on the definition of unemployment recently proposed by a Technical Commission appointed by the International Labour Office at Geneva. That definition ran as follows: 'Unemployment may be defined as the condition of a

[87] Beveridge, *Unemployment*, p. 105, and Index under *Trade Unions*.

worker who is both able and willing to work but is unable to find employment *suitable to his qualifications and reasonable expectations.*' The implication of such a clause in a European country is indicated in the approving comment of the Government of Finland: 'Skill in a trade and the possibilities of remuneration depending thereon generally fix the reasonable expectations of a worker.' On the other hand, the Governments of new countries like Canada and South Africa are unwilling to recognise the claim which seems to be involved in 'reasonable expectations.' The explanation is that the industrial conditions are in fact very different. This is well explained by the Government of South Africa: 'In the Union, with the exception of clearly defined trades . . . workers do not confine themselves to specified occupations, as they do in older countries where occupations and industries are more sharply defined or firmly established.'[88]

In a work which is among the most outstanding products of English economic inquiry in the present century, and which has had powerful influence on English legislation, I find the sentence: 'Adam Smith and his followers were right in emphasizing the mobility of labour as the cardinal requirements of industry.'[89] In the table of contents this appears as: 'The demand of economists for mobility of labour.' Adam Smith and his immediate followers did indeed 'demand' it, as itself a good thing in the interests of production. Later economists have sometimes been more cautious and have 'demanded' it, but only as a postulate of their deductive reasonings, without committing themselves to an opinion as to its own merits. To assume its merits, without sufficient regard to contemporary conditions, and to base the establishment of a widespread governmental organisation upon this one 'demand,' is likely to lead to some disappointment with the results—as has been in the case with the British Labour Exchanges.

When a long-established industry in England has been seriously damaged—as has, of course, occurred again and again—by changes in foreign tariffs, it has, I think, seldom happened that it has entirely disappeared. It may permanently contract into narrower dimensions, and in the next generation its place in a particular town may be taken by another and newer industry. In this case its disappearance will have been attended by an amount of suffering and, what is worse, of demoralisation which 'friction' hardly indicates. Or in another ten years it may have obtained new markets in other lands, and its output may be as large as ever. In this case we shall be told what an admirable thing is freedom in stimulating the enterprise of manufacturers and compelling them to improve their methods. That it sometimes does both, I do not dream of denying. But the deterioration of character which does so easily beset workpeople during protracted periods of unemployment or under-employment is at least as important a fact as the blessings of the subsequent rebound.

And there is this to be added that, just as the old doctrine of the national capital exaggerated its fluidity within a country when already invested in plant, and minimised its fluidity as between countries when newly created, so the doctrine of the national labour-force overestimated its transferability

[88] *Methods of Compiling Statistics of Unemployment.* Intern. Labour Office: Studies and Reports, Series C. Unemployment No. 7. Geneva, 1922. See pp. 9, 10, 11, 16.

[89] Beveridge, *Unemployment*, p. 216.

from industry to industry within an old country, and overlooked the possibility of its transference to the same industry in another country. The migration of skilled labour to carry on its old occupation in a protected country does not take place on so large a scale as the migration of fresh manufacturing capital. But it has taken place repeatedly and is taking place now. And whether we in England or any other of the older countries view the phenomenon with complacency or concern, it presents a different picture to our eyes from that which was present either to Smith or to McCulloch.

9. The last of the large ideas which characterised the period we are considering is the unique emphasis it laid upon cheapness to the consumer as the test of social policy. I shall not go beyond Adam Smith for this. I will only quote three well-known passages. In the first he says: 'In every country it always is and always must be the interest of the great body of the people to buy whatever they want of those who sell it cheapest. The proposition is so very manifest that it seems ridiculous to take any pains to prove it.'[90]

In the second, with the same crushing air of certitude: 'Consumption is the sole end and purpose of all production; and the interest of the producer ought to be attended to, only so far as it may be necessary for promoting that of the consumer. The maxim is so perfectly self-evident, that it would be absurd to attempt to prove it.'[91]

The third passage is a compact summary of the system he founded. It is that in which he speaks, as it were in passing, of 'the cheapness of consumption and the encouragement given to production' as 'precisely the two objects which it is the great business of political economy to promote.'[92]

I remember, when I was at Harvard, going, in the company of Francis Walker, to dine at the house of Edward Atkinson. None could know Atkinson without liking him; and we had personal reasons that evening for being interested in 'the Atkinson Cooker.' But all I remember of the economic discussion which followed the repast was Walker's snort of speechless protest when Atkinson explained that to buy in the cheapest market and sell in the dearest was to carry out the Golden Rule. I thought it was only a playful extravagance on Atkinson's part, but original. I had not read my Cobden then as I have since had occasion to do. I did not know that the identification which startled Walker out of his politeness forms the concluding paragraph of one of Cobden's great speeches.[93] I had forgotten, also, that moving passage in one of his pamphlets in which Cobden declared that, in place of many of the glittering mottoes of our forefathers, 'we must substitute the more homely and enduring maxim—*cheapness*, which will command commerce; and *whatever else is needful will follow in its train*.'[94]

Some of the criticisms one comes across of Cobden are, one must confess, a little hasty. As the organiser of the first Faculty of Commerce in a British University, I should be the last to deny the vast importance of

[90] *W. of N.*, Bk. IV., ch. iii. (II., 68.)
[91] Bk. IV., ch. viii. (II., 244.)
[92] Bk. V., ch. i. (II., 333.)
[93] Feb. 27, 1846.
[94] *Russia* (1836), in *Political Writings*, p. 125.

Price. And I by no means suppose that all the pleas for particular tariffs in order to keep up the workmen's standard of living have been well founded. All that I wish to say, after such a survey of a past period as we have been engaged upon, is that economic life has ceased to be as simple, if it ever were as simple, as those two great men, Adam Smith and Cobden, seemed to think it. It has not been so clear to the last half-century as it was to them that human well-being can be achieved by the application of one symmetrical cycle of principles. By the whole current of its industrial legislation the civilised world has protested against the all-sufficiency of cheapness. It has now embarked upon the double task of making a Living Wage a first charge upon the community and of giving Security a larger place in industrial life. This will be a harder business than to abolish old and often outworn restrictions on 'natural liberty.' Society has been so sorely disappointed in the hope that, if it sought first cheapness, all other needful things, like social peace, would be added to it, that it is in the mood to 'explore other avenues,' as the phrase goes—avenues as yet imperfectly charted.

SECTION G.—ENGINEERING.

A HUNDRED YEARS OF ELECTRICAL ENGINEERING.

ADDRESS BY

PROFESSOR G. W. O. HOWE, D.Sc.,

PRESIDENT OF THE SECTION.

THIS Section of the British Association, over which I have the honour to preside, is concerned with the whole field of engineering, civil, mechanical and electrical. Within recent years the great developments which have taken place in each of these branches have necessarily led to a high degree of specialisation, with the result that a man may have an expert knowledge of one branch but a very slight knowledge of the other branches; in fact, the scope of a single branch is now so extensive and the amount of research work being done so great that it is impossible to keep abreast of the developments in one's own special subject unless one concentrates upon it to a degree that leaves little leisure for cultivating other branches of engineering. These considerations influenced my choice of a subject for this Presidential Address. As an electrical engineer, I felt that I should be expected to deal with some branch of electrical engineering—indeed, I should not feel competent to discuss any other branch—but, in view of the facts to which I have referred, I decided not to deal in detail with any single section of the subject, but to review the past development and present position of the subject as a whole.

The time for such a review is opportune. William Thomson, afterwards Lord Kelvin, the only man who has ever been elected three times (in 1874, 1889, 1907) President of the Institution of Electrical Engineers, was born on June 26, 1824. He was closely associated with the British Association and for sixty years took an important part in the meetings. He was President of the Association at the Edinburgh Meeting in 1871, and was several times President of Section A. I wonder what the members of the organising committee of Section G would think if the President, in addition to reading his address, offered to contribute twelve papers to the Proceedings of the Section: this is what Kelvin did as President of Section A at the Glasgow Meeting in 1876. I can find no record of his taking any part in the proceedings of Section G, although his brother, James Thomson, was President of the Section at the Belfast Meeting in 1874.

If any one event can be regarded as the birth of electrical engineering, it is surely the discovery by Faraday in 1821 of the principle of the electromotor; that is, that a conductor carrying a current in a magnetic field experiences a force tending to move it. It is noteworthy that ten years elapsed before Faraday discovered, in 1831, magneto-electric induction; that is, the principle of the dynamo. Four years later, Sturgeon added the commutator or 'uniodirective discharger,' as he called it, and in 1845

Cooke and Wheatstone used electromagnets, which Sturgeon had discovered in 1825, instead of permanent magnets. It was during the years 1865-1873 that the shunt and series self-excited dynamo, using a ring or drum armature and a commutator of many segments, finally evolved.

The early workers in the field do not appears to have realised the intimate connection between the dynamo and the motor, for, although the principle was discovered by Lenz in 1838, it only appears to have become generally known that the same machine could be used for either purpose about 1850. The principle underlying the whole modern development of electrical engineering—viz., the generation of electrical power by a dynamo, its transmission to a distant point and its re-transformation to mechanical power by an electric motor—appears to have evolved about 1873. An interesting light is thrown on the subject by a paper read before the Institution of Civil Engineers in 1857 by Mr. Hunt on 'Electromagnetism as a Motive Power.' In this paper, the possibility of driving electromagnetic engines—that is, electric motors—by currents derived from voltaic batteries was discussed in the light of Jacobi's discovery of the back-electromotive force in these machines. He concluded that power so generated would be sixty times as dear as steam-power, and that it would be far more economical to burn the zinc under a boiler than to consume it in a battery for generating electromagnetic power. The leading scientists and engineers who took part in the debate all agreed that electromotive power was unpractical and impossible commercially. William Thomson sent a contribution in writing which concluded with the following sentence: 'Until some mode is found of producing electricity as many times cheaper than that of an ordinary galvanic battery as coal is cheaper than zinc, electromagnetic engines cannot supersede the steam engine. As S. P. Thompson says, 'Faraday's great discovery of 1831 notwithstanding, the real significance of the dynamo had not yet (in 1857) dawned upon the keenest minds of the time.' Six years before this, Thomson had suggested the experiment of driving a 'galvanic engine' from a thermal battery, and had stated the problem in terms which show that he already had a correct grasp of the theory of the efficiency of the electric motor.

It was at the Manchester Meeting of the British Association in 1861 that Charles Bright and Latimer Clark read a paper proposing names for the principal electrical units; the names were 'galvat' for current, 'ohma' for electromotive force, 'farad' for quantity, and 'volt' for resistance. This paper led to the appointment of the celebrated Electrical Standards Committee of the British Association, which, after six years of strenuous work, produced the system now adopted internationally.

One of the earliest applications of the dynamo was for lighting arc lamps in lighthouses; in 1863 Thomson, writing to a friend on the relative merits of the Holmes direct-current and the Nollet alternating-current lighthouse machines says, 'Thus Nollet escapes the commutator, *a great evil*, and gets a flame which does not burn one of the points faster than the other. The reverse of each proposition applies to Holmes. *The commutator is a frightful thing* . . . the thing to be done at the requisite speed is appalling. However, Holmes does it successfully. But I believe it cannot be done except theoretically without great waste of energy and consequent burning of contact surfaces. . . . *But I believe a large voltaic battery will be*

more economical than any electromagnetic machine. I am not quite confident about this, but shall be so soon, as I am getting a large voltaic, and I shall soon learn how expensive its habits are, and multiply by the number required for a lighthouse.' This was thirty-two years after Faraday had discovered the principle of the dynamo.

In after years Kelvin lost his dread of the commutator and championed direct against alternating current on every possible occasion. In 1879, when giving evidence before a Select Committee of the House of Commons on Electric Light, he even assured them that there would be no danger of terrible effects from the employment of electric power, because the currents would be continuous and not alternating!

The fifteen years following 1863 saw a great development of the dynamo, and in 1878, when a paper was read before the Institution of Civil Engineers on the improvements introduced by Siemens, Thomson made a remark, following a suggestion by Dr. C. W. Siemens, that showed that he had by this time thoroughly grasped the possibilities. He said that he believed that with an exceedingly moderate amount of copper it would be possible to carry the electrical energy for one hundred or two hundred or one thousand electric lights to a distance of several hundred miles. Dr. Siemens had mentioned to him that the power of the Falls of Niagara might be transmitted electrically to a distance, and he need not point out the vast economy to be obtained by the use of such a fall as that of Niagara or the employment of waste coal at the pit's mouth. In his evidence before the Select Committee referred to above he gave an estimate of the copper required to transmit 21,000 horse-power from Niagara to a distance of 300 miles.

In 1881 Thomson returned to the subject in his Presidential Address to Section A at York and said, 'High potential, as Siemens, I believe, first pointed out, is the essential for good dynamical economy in the electric transmission of power.' He mentioned 80,000 volts as a suitable voltage. In a paper before the Section he developed the now well-known Kelvin Law of the most economical cross-section of the conductor. In 1890 the American promoters of the project for utilising the power of Niagara turned to Thomson for his advice, and he became a member of the Commission of Experts. He was throughout stubbornly opposed to the use of alternating currents; he wrote, 'I have no doubt in my own mind but that the high-pressure direct-current system is greatly to be preferred to alternating currents. The fascinating character of the mathematical problems and experimental illustrations presented by the alternating-current system and the facilities which it presents for the distribution of electric light through sparsely populated districts have, I think, tended to lead astray even engineers, who ought to be insensible to everything except estimates of economy and utility.' He was in a hopeless minority, however, in this view, and the Falls of Niagara were harnessed to two-phase alternators with an output of 3,500 kilowatts each. Kelvin was present at the meeting of the British Association held in this city in 1897, and shocked many people by saying that he looked forward to the time when the whole water of Lake Erie would find its way to the lower level of Lake Ontario through machinery; 'I do not hope,' he said, 'that our children's children will ever see the Niagara Cataract.' Although he was apparently very much impressed with the success of the Niagara system, he was not converted

from his allegiance to direct currents, for at his last appearance at the Institution of Electrical Engineers, in 1907, he said, 'I have never swerved from the opinion that the right system for long-distance transmission of power by electricity is the direct-current system.'

The development of the dynamo during the seventies and the simultaneous development of the incandescent lamp led to the general introduction of electric light during the eighties. Attempts to make incandescent electric lamps had been made as early as 1841, when de Moleyns patented one having a spiral platinum filament, and in 1847 Grove illuminated the lecture theatre of the Royal Institution with such lamps, the source of power being primary batteries; but it was not until 1878 that the commercial development of the incandescent electric lamp was begun by Edison and Swan.

One of the earliest complete house-lighting installations was put in by Kelvin in 1881. A Clerk gas-engine was used to drive a Siemens dynamo, a battery of Faure cells was fitted up, and every gas-light in his house and laboratory at Glasgow University was replaced by 16 candle-power Swan lamps for 85 volts. He had to design his own switches and fuses, etc., for such things were almost unknown.

For about twenty years the carbon-filament lamp held the field without a rival for interior illumination, and, although attempts were made to improve its efficiency by coating the filament with silicon, the plain carbon filament only gave way finally to the metal-filament lamp. One of the most interesting developments in the history of electric lighting was the Nernst lamp, which was introduced in 1897; the filament consisted of a mixture of zirconia and yttria, and not only had to be heated before it became conducting but also had to be connected in series with a ballast resistance in order that it might burn stably. The way in which these difficulties were surmounted and the lamp, complete with heater, ballast resistance, and automatic cut-out, put on the market in a compact form occupying little more space than the carbon-filament lamp was, in my opinion, a triumph of applied science and industrial research. The efficiency was about double that of the carbon lamp. About this time, however, a return was made to the long-neglected metal filament. The osmium lamp invented by Welsbach in 1898 was put on the market in 1902, to be followed two years later by the tantalum and tungsten lamps. The latter was greatly improved by the discovery in 1909 of the method of producing ductile tungsten and by the subsequent development of gas-filled lamps in which the filament can be run at such a temperature without undue volatilisation that the consumption is reduced in the larger sizes to 0·6 watt per mean spherical candle-power. This improvement of eight times as compared with the efficiency of the carbon-filament lamp has led to the gradual replacement of the arc lamp even for outdoor illumination. The arc lamp was introduced at about the same time as the carbon-filament lamp, the Avenue de l'Opéra having been lit with Jablochkoff candles in 1878. The open arc was developed during the eighties; the enclosed arc, giving long burning hours and thus reducing the cost of re-carboning, was introduced in 1893, and the flame arc in 1899. During the first few years of this century the flame arc was brought to a high stage of development and the consumption brought down to about 0.25 watt per candle-power, but the necessity of frequent cleaning to prevent the reduction of efficiency by dirt and the

labour of re-carboning have led to its abandonment in favour of the less efficient filament lamp.

Before leaving the subject of electric lighting I would point out that it is remarkable that the first great application of electric power should have been for the production of electric light, since it is probably the least efficient of all its applications. The overall efficiency of a small power station supplying a lighting load and having therefore a very poor load factor would not be greater than about 6 per cent. from coal to switchboard, the steam-engine being, of course, the principal offender. Of the total power supplied to and radiated from a carbon-filament lamp not more than about 2 per cent. was radiated as light, so that the overall efficiency from coal to light was 2 per cent. of 6 per cent., which means that of every ton of coal burned at the power station with the object of producing light all but about 3 lb. was lost as heat at various stages of the transformation. Even now, with up-to-date steam plant and gas-filled lamps, the overall efficiency from coal to light is not equivalent to more than 40 to 60 lb. of coal out of each ton. The electrical engineer may derive a little comfort from the knowledge that the purely electrical links are the most efficient in the chain.

Whilst on the subject of efficiency I might point out that the difference between the prices at which coal and electrical energy can be purchased by the ordinary citizen corresponds to the losses incurred in the power station; that is to say that the cost of the generation and distribution of the electrical energy is covered by the better terms on which the power station can obtain fuel. In Glasgow the writer pays 5*l.* per ton for anthracite to burn in a slow-combustion stove; taking the calorific value of anthracite at 9,000 kilowatt-hours per ton, which is equivalent to 14,000 British thermal units per lb., this works out at 7½ kilowatt-hours for a penny. For electrical energy for heating and cooking purposes the writer pays a penny per kilowatt-hour. This ratio of 1 to 7½ will correspond fairly closely to the overall efficiency of the power station. In view of the high efficiency and convenience of slow-combustion stoves, it is evident that electric heating cannot be expected to compete with them for continuous operation; for intermittent heating the question is very different.

Returning from this digression to the development of the direct-current dynamo, it may be noted that the drum armature now almost exclusively employed was invented in 1872 by von Hefner Alteneck, and gradually displaced the ring armature of Pacinotti and Gramme. Although Pacinotti's original ring armature was slotted, smooth armatures were preferred for many years, until the mechanical superiority of the slotted armature caused the disappearance of the smooth core with its wooden driving pegs which were employed to transmit the turning moment from the conductors to the core. The commutator and brushes were a great source of trouble, but by the gradual elimination of unsuitable material and by better design and methods of manufacture the commutator has been made a most reliable piece of apparatus. The difficulties of commutation, and especially the need of continual adjustment of the brush position, were largely overcome by the invention of the carbon brush by Professor George Forbes in 1885. It should be pointed out that the commutating poles, which have come into use so much in recent years, were originally suggested in 1884, and are therefore older than the carbon brush.

The realisation of the idea of supplying electric current from a power station for lighting houses in the neighbourhood owed much to the energy and business ability of Mr. Edison. He exhibited his first 'Jumbo' steam-driven dynamo in 1881, and installed two sets at Holborn Viaduct in the following year to supply current to neighbouring premises. The output of these sets was about 90 kilowatts at 110 volts, which was so much larger than anything previously constructed that the name 'Jumbo' was applied to these sets. About 1890 the multipolar type began to replace the bipolar type for the larger sizes. The size of the single units employed in power stations gradually increased with the increasing demand, and by 1895 dynamos of 1,500 kilowatts had been installed.

As in all other types of machinery, the output obtainable from a given size has been gradually increased by improvements in the electrical, magnetic, and mechanical properties of the materials employed, and by improving the design so as to remove ever further the limits imposed by heating, sparking, voltage drop, etc. The freedom from trouble of the enormous number of electric trams and trains, to take only one class, is a testimonial to the reliability of the modern direct-current motor.

The alternator has had a more varied development than the dynamo, mainly because of the absence of the commutator. The necessity of keeping the brush gear stationary and accessible and therefore allowing the commutator and armature to rotate led to an early standardisation of type in the D.C. machine. In the alternator there was no such limitation, and whether the field system should be inside or outside the armature and which of the two should rotate were largely matters of choice. There are great advantages in having the armature, which usually carries a high-voltage winding, stationary, and the usual practice has been for the field system to rotate within the armature. The most striking and best-known exception is the umbrella type of alternator installed in the first Niagara power station, in which the field system rotates outside the armature. The design of alternators has been controlled to a large extent by the development of the prime mover. On the Continent of Europe the slow-speed horizontal steam-engine led to the construction of alternators of enormous diameter in order to get the necessary peripheral speed, the axial length being consequently reduced to a few inches. In several cases these machines reached such a height that the travelling cranes in the erecting shops were useless, and special tackle had to be erected in order to assemble the machines. In England the high-speed marine-type engine was generally preferred, and consequently the alternators had a smaller number of poles and a smaller diameter. All this has now been modified by the development of the steam turbine.

Ferranti was apparently the first to suggest that the power station should be outside the city, at a point convenient for fuel and water supply, and that the power should be transmitted into the city by high-voltage alternating currents. In 1890 he built the Deptford Station for the London Electric Supply Company, and installed 1,000-kilowatt 10,000-volt alternators. This was the pioneer high-voltage underground cable transmission, and much was learnt concerning the peculiarities of alternating currents when transmitted over cables of considerable capacity. The following year, 1891, saw the first long-distance transmission by means of overhead conductors in connection with the electrical exhibition at Frankfort-on-

Main; three-phase power was transmitted, at 8,500 volts, from a water-power station at Lauffen to Frankfort, a distance of 110 miles.

This development of the use of high-voltage alternating currents followed the development of the transformer. Gaulard and Gibbs patented a system of distribution involving transformers in 1882, and, although their patent was upset in 1888 on the ground of its impracticability, the present method of using transformers for the distribution of electrical power was introduced in 1885, and shown at the Inventions Exhibition in London in that year. Although from 1890 onwards there has been a steady increase in the size of alternators and transformers and in the voltage employed for long-distance transmission, the last few years have seen a really amazing increase in the size of the units employed. In 1913 the largest 2-pole turbo-alternators had an output at 3,000 revs. per minute of about 7,500 kilowatts; such machines are now made up to 30,000 kilowatts, and 4-pole alternators are running at 1,500 revolutions per minute, with an output of 60,000 kilowatts. This increase in size and in peripheral speed has been made possible by improvements, both in the material and in the design. With a bursting speed 25 per cent. above the running speed, the peripheral speed can now be raised to 150 metres per second. Improved methods of cooling and a better understanding of the various causes of loss in the armature have enabled the materials to be used at higher current and flux densities.

This great increase in the size of units is not confined to the steam turbo-generator, as can be seen from the water-turbine sets recently added to the Niagara installation. Whereas the original Niagara turbines were of about 5,000 horse-power, the new ones have an output of 70,000 horse-power at the low speed of 107 revolutions per minute.

The importance of cheap electric power has led to this great increase in the size of the units in the generating stations. Any slight difference of efficiency between a 10,000-kw. and a 60,000-kw. alternator is of little importance, and would certainly not counterbalance the decreased factor of safety due to concentrating the whole power supply in three or four large units, instead of distributing it between a dozen or more units. The reason for the adoption of the smaller number of large units lies almost entirely in the decreased capital cost per kilowatt of plant. In my opinion, however, there are many cases in which too much consideration has been given to this factor, and too little to the importance of a guaranteed continuity of supply.

Of even greater interest than the growth in the size of the units in the power station is the development of the switch control and protective gear, which is such an essential element in the success of the modern power plant. In the early days of electrical supply all the switch-gear was mounted on slate panels in the engine-room; then, as the power and voltage increased, the switches were placed above, below, or behind the board and operated by mechanical links; then they were removed to another part of the building, each enclosed in its own fire-proof cubicle, and operated by means of relays. The modern high-power switch, like the transformer, is oil-immersed in its iron containing case, and is so robust and weather-proof that it needs no further protective covering, but can be placed in the open air. The insulated bushings through which the leads are taken into the case are the most vulnerable points, but constitute no insuperable difficulty at the present time.

The development of these robust and weather-proof switches and transformers has led to the introduction of the open-air sub-station in cases where alternating current has to be transformed from one voltage to the other, and there is consequently no running machinery. In generating stations also much of the controlling and transforming plant which was formerly housed in the building can now be placed outside, with considerable saving on the cost of the building.

In connection with the conversion of alternating to direct current, mention should be made of the mercury arc rectifier. Great improvements have been made in recent years, especially in Switzerland, and a number of high-power arcs have been installed in sub-stations. Although they have the advantage of doing away with running machinery, the modern rotary-converter is such a reliable piece of apparatus that it is very questionable whether it will be replaced to any considerable extent by the mercury arc rectifier.

Until recently, the only means of producing a large amount of high-voltage D.C. power was by connecting a large number of carefully insulated dynamos in series, as in the well-known Thury system of power transmission. Within the last two or three years another method has been developed, viz., the so-called transverter, which consists of an arrangement of transformers and a system of rotating brushes, whereby a three-phase A.C. supply is converted into an almost steady continuous current. The first apparatus of this type to be exhibited is installed at the British Empire Exhibition at Wembley, and is designed to deliver continuous current at 100,000 volts. It can also be used for the reverse process. It would thus enable a three-phase generating station and a three-phase sub-station to be connected by a direct-current transmission line, thus avoiding not only the maximum voltage of 1.4 times the effective voltage, which was one of Lord Kelvin's objections to the A.C. system, but also all trouble due to the capacity and inductance of the line. Whether the disadvantages of the transverter, when it is fully developed—it is yet in its infancy—will more than outweigh these advantages remains to be seen, but, apart from the transmission of power, the device may have many applications.

Electric traction represents one of the most important branches of electrical engineering. It shares with the petrol motor the distinction of having absolutely revolutionised the methods of transport within a single generation. In its origins it is nearly a century old, for attempts were made in the thirties to apply Faraday's newly discovered principle to the propulsion of vehicles, but, with very primitive motors and primary batteries, these attempts were doomed to failure. The development of the dynamo and motor in the seventies opened the way to further experiments, and at the Berlin Exhibition in 1879 a line one-third of a mile long was shown in operation, a locomotive drawing three cars. The first regular line was opened to traffic near Berlin in 1881; it worked at 100 volts and the current was collected from an insulated rail. Toronto was the scene of one of the earliest experiments in America; C. J. van Depoele, after some experiments at Chicago in 1882 and 1883, ran an electric locomotive in 1884 between the street-car system and the Exhibition in Toronto.

The difficulties were enormous. The carbon brush was not invented

until 1885, and commutation in a reversible motor with copper brushes caused great trouble; armature construction and winding was in its infancy; the suspension of the motor and the method of gearing it to the car axles were problems which were solved only after much experience. Rapid progress was made after about 1887, and the closing years of the century saw an enormous development, the elimination of horse tram-cars throughout the world and the electrification of a number of city and suburban railways.

Of the various systems of collecting the current, only two have survived for street-cars, viz., the usual overhead wire and the exceptional underground conduit; in the case of railways there is no necessity for a conduit and the conductor rail is carried on insulators above the ground-level.

Although 500-volt D.C. supply has been standardised for street tramways, the relative merits of D.C. and A.C. for electric railways has been a burning topic for over twenty years, and is now perhaps more burning than ever. It is somewhat akin to the battle of the gauges in the early days of steam railways, for it involves in many cases the problem of through running, if not now, in the not very distant future. Although the three-phase system was successfully installed in Northern Italy, it has grave disadvantages, and the battle now is confined between direct current at an increased voltage of, say, 1,500 to 2,000 volts, and single-phase alternating current. In the latter case there is, moreover, a further question as to the best frequency to adopt, this being usually either 25 or $16\frac{2}{3}$. The development of the A.C. commutator motor to the stage where it was applicable to traction took place during the first few years of this century, and, although in itself it is inferior to the D.C. motor, it introduces so many simplifications and economies in the transmission of the power from the generating station to the train that experts are very divided as to the relative merits of the two systems for main-line electrification.

I can only just refer to the applications of electrical power to chemical and metallurgical processes. Some of these are purely electro-chemical, others are purely thermal, while in many processes the electric current performs the double function of melting and electrolysing. The possibility of electroplating was discovered as early as 1805, but the commercial application of electro-chemistry on a large scale was impossible before the development of the dynamo. Within the last thirty years the provision of an abundant supply of electrical power has led to the creation of enormous electro-chemical industries; I need only instance the production of aluminium, carborundum, and calcium carbide. These industries have usually been established near a hydro-electric plant and provide a load of very high load-factor.

I turn now to what may be called both the earliest and the latest application of electricity; that is, its use for transmitting intelligence. One of the greatest factors in the development of our modern life has undoubtedly been the network of wires and cables which has spread over the whole earth, making possible an almost instantaneous transmission of intelligence and interchange of opinions. In the early days of electrical science the discovery of a new property of electricity was followed by attempts to utilise it for this purpose. As early as 1746 there are records of the use of frictional

electricity for the purpose, and distances up to four miles were tried. In 1774 Lesage of Geneva proposed 26 wires in earthenware pipes with pairs of pith-balls at the end of each wire, which flew apart when the conductor of a frictional machine was brought near the other end of the wire. A current of electricity was unknown until Galvani's discovery in 1789, and Volta's pile was first constructed in 1792. Carlisle in 1800 found that water was decomposed by passing the current from a Volta pile through it, and this was the basis of the telegraph proposed by Sömmering in 1809, in which 26 wires ended in 26 metallic points arranged in a row along the bottom of a kind of aquarium. By means of a lettered keyboard at the sending end the current could be applied to any wire, and a stream of bubbles caused to rise from the appropriate point, each point being duly labelled with its appropriate letter. The magnetic effect of the electric current was discovered in 1819, and immediately replaced the previous methods in efforts to develop an electric telegraph; except for the attempts to make a high-speed chemical telegraph, all subsequent telegraph systems have employed the magnetic effect of the current. A great many of the fundamental inventions of telegraphy were made in the thirties; the list includes the needle instrument of Cooke and Wheatstone, the sounder of Henry, the dot-and-dash inker of Morse, and the use of the earth as a return by Steinheil. Although the needle instrument is now obsolete, the sounder and Morse inker are still commonly employed. Many have been the devices for increasing the amount of traffic which can be worked over a single line, either by the simultaneous use of the line by a number of operators, as in the quadruplex and multiplex systems, or by punching the messages on paper tapes, which can then be fed into an automatic transmitter working at a speed ten to twenty times that attainable by a manual operator. In the most up-to-date systems the perforation of the tape is done by the operators working an ordinary typewriter keyboard, and the received message is printed in ordinary type, a single wire carrying eight messages simultaneously, four in either direction, at a speed of 40 words per minute.

The need for telegraphic communication between countries separated by water was so much the greater because of the slowness of other means of communication, but the difficulties in laying and maintaining 2,000 miles of insulated wire on the bottom of the sea must have appeared almost insuperable to the early workers; fortunately, however, there were men who had the necessary vision and courage. The flimsiness of the early cables suggests that the pioneers underestimated the magnitude of the problem which faced them, which was perhaps fortunate. A cable was laid between Dover and Calais in 1850; it lived only a single day, but it was replaced in the following year by a successful cable.

The first cable was laid across the Atlantic in 1858, and, although in the light of our present knowledge we know that it could not have had a very long life, its failure after a few weeks of preliminary communication was primarily due to misuse owing to the ignorance of those in charge. Although much costly experience had been gained in the laying of cables in various parts of the world since this first attempt to span the Atlantic, the success of the second Atlantic cable in 1866 was largely due to the scientific ability of Kelvin and to his enthusiastic and untiring application to the project at every stage of the manufacture and laying of the cable. In addition to this, he not only designed the receiving instruments, but

superintended their manufacture in Glasgow and their installation and operation. The success of the Atlantic cable was to a large extent a personal triumph for Lord Kelvin. Although numerous improvements have been made in the details of cable manufacture and in the transmitting and receiving apparatus, no outstanding change has been made in recent years in the methods of submarine telegraphy.

Turning to another branch of electrical communication, it is no exaggeration to say that modern business life has been revolutionised by the telephone, which will shortly celebrate its jubilee, for it was in 1876 that Graham Bell invented the magnetic telephone receiver, although others, notably Reis, had been working at the problem since 1861. Bell showed his telephone in operation at the Philadelphia Centennial Exhibition in 1876, and Kelvin, who was one of the judges, brought one back with him and demonstrated it to Section A of the British Association, at its meeting in Glasgow in the autumn of 1876.

A successful telephone system requires much more than efficient transmitters and receivers, and the great development which has taken place has been largely a matter of improvement in the design of the many elements that go to make up a telephone exchange. The modern manual central-battery exchange, in which one has only to lift his receiver to call the operator and be connected in a few seconds to any one of 10,000 other subscribers, is a marvel of ingenuity and construction. But this is now gradually being replaced by the greater marvel of the automatic system, in which the operator is eliminated and the subscriber automatically makes his own connection to the desired subscriber. Attention should be drawn to two outstanding inventions in the actual transmission of telephony over long distances, viz., loading and repeaters. It was Oliver Heaviside who in 1885 proposed to improve the range by increasing the inductance of the line. Although this revolutionary suggestion fell on deaf ears for fifteen years, it ultimately proved to be one of the great inventions of telephony; it is of special importance in underground and submarine telephone cables, the electrostatic capacity of which otherwise seriously limits the range. The other outstanding novelty is the introduction of repeaters at intermediate points in long telephone lines. These repeaters are specialised types of low-frequency amplifiers; they were made commercially possible by the invention and perfection of the three-electrode thermionic valve. The attenuated speech currents arriving at the end of a section of line are amplified and thus given a new lease of life before being passed on to the new section. By using a large number of such repeating stations, telephonic communication has been established between New York and San Francisco. But in addition to making such long-distance communication possible, the use of repeaters enables medium distances to be bridged by relatively cheap lines of high attenuation.

One important application of telephony which is not generally known is in the control of transport; the advantage to be gained by controlling the whole railway traffic of a large district from a central office need only be mentioned to be appreciated.

Turning now to radio telegraphy and telephony, one cannot but marvel at the rapidity of its development and the inroad that it has made during the last two or three years on the domestic life of the whole civilised world. The theory of Clerk Maxwell in 1864 and the laboratory experiments of

Hertz in 1888 found their first practical application in Marconi's Italian experiments in 1895 and his demonstrations in England during the following year. Much of the rapid progress was due to his perseverance, vision, and courage in perfecting apparatus for short-distance work, and simultaneously experimenting over long distances, and thus, in the year 1901, settling by actual demonstration across the Atlantic the vexed question as to whether the waves would pass around the earth over distances of several thousand kilometres or go off into space.

The accomplishment of long-distance communication bristled with difficulties, largely due to unsuspected atmospheric effects which are still little understood; but such progress has been made and is continually being made that one dare not now adopt an incredulous attitude to the wildest dreams or forecasts of what is to be accomplished by 'wireless.' The commonplace facts of to-day would have appeared beyond the bounds of possibility ten or twenty years ago.

I have attempted to trace, in a necessarily somewhat superficial, but, I trust, none the less interesting, manner the development during the last hundred years of some of the principal applications of electricity to the service of mankind. In preparing this address, I have been greatly impressed by the enormous advances made, especially during the last thirty or forty years, in the mastery of man over the resources of nature, and in the use of these resources to the amelioration of the conditions of life. By the aid of electricity the energy of the coal or of the lake or river a hundred or even two hundred miles away is transmitted noiselessly and invisibly to the city, to supply light and warmth, to cook the food, to drive the machinery, to operate the street-cars and railways.

By its aid one can flash intelligence to the most distant part of the globe, hold conversations with friends hundreds or even thousands of miles away, or sit in one's home and listen to music and lectures broadcast for the entertainment or instruction of all who care to equip themselves with what may almost be regarded as a new sense. Whereas thirty years ago a ship at sea was completely isolated from the life and thought of the world, it is now in continuous communication with the land and with every other ship within a wide range.

In no branch of electrical engineering, however, is there any suggestion of having reached finality; on the contrary, rapid development is taking place in every direction, and we can look forward with confidence to an ever-increasing application of electricity to the utilisation and distribution of the natural sources of energy for the benefit of mankind.

SECTION H.—ANTHROPOLOGY.

HEALTH AND PHYSIQUE THROUGH THE CENTURIES.

ADDRESS BY

F. C. SHRUBSALL, M.D., F.R.C.P.,

PRESIDENT OF THE SECTION.

A Canadian meeting of the British Association for the Advancement of Science is of special interest to Section H, since it was in this Dominion that it first entered upon a separate existence forty years ago.

In his Presidential Address to the Section at the Winnipeg meeting, Professor Myres asked the question 'What happens to Englishmen in city "slums"?' or, in other words, how are the peoples of Britain adapting themselves to modern conditions? Are these conditions producing modifications in the racial constitution and qualities of the nation? The matter is one of importance to the older country, for over three-quarters of the population now reside in urban districts, and to the newer, since in the course of time industries must concentrate in favourable localities and close aggregates of population necessarily arise.

The trend of events can be followed in outline from demographic data from about the fourteenth century, though the records are scanty until the nineteenth century. The main factors are urbanisation and industrialism, the combined effects of which can be seen best, though in an exaggerated form, in those individuals who follow certain trades, such as the textile industry, which associate dense aggregation with, even at the best, unhealthy conditions of occupation.

Indoor trades and factory life introduce very different physiological conditions from those under which the young peasant has his being. These factors tend to depress the vitality of the incomer from the country, while those born in the industrial township would be exposed to urban conditions throughout early as well as adult life, and have the further handicap in infancy of the lack of care inevitably associated with the factory employment of the mothers.

In addition, selection may in time sensibly modify the distribution of the various racial elements of the population. Psychological factors, too, come into play, for some types seem to prefer the freer life of the open spaces and leave a district as it becomes more densely settled; while others, who have no love or aptitude for solitude, migrate into the growing towns. The early settlers of the North American continent were drawn largely from areas occupied by Nordic peoples whose early history was that of hunting and fighting communities. As the eastern edge of the continent became settled, it was this type that was largely represented in the pioneers of the West.

At first sight, the answers to the questions seem to be unsatisfactory, and it is common to hear of the physical deterioration of the people, though such pessimism is of long standing, being found as early as 'The Reflections of an Egyptian Sage.' It seems worth while to inquire if the change is real and permanent.

The most alarming data in regard to the position in Britain come from the Report of the Ministry of National Service on the findings of the recruiting boards during the last years of the European war. The recruits were graded into four categories, from those who exhibited the full normal standard of health and strength and a capacity to sustain severe exertion, through those with various partial disabilities, down to those totally and permanently unfit for any form of military service. The ages of those examined extended from eighteen to fifty, and the report therefore comprised such a study of a selected sample of a people as had never before been attempted. The survey of some two and a half million men showed them to be graded in the proportions[1] :—

Grade I.	..	36 per cent.
Grade II.	..	23 per cent.
Grade III.	..	31 per cent.
Grade IV.	..	10 per cent.

Grave disappointment followed this discovery; but a reassuring comment was made by the Commissioner for Yorkshire,[2] who pointed out that grading for military purposes must, in many essentials, differ from grading in respect to fitness for civilian life, which, after all, is the factor of most permanent importance to a nation. For example, an exaggerated flat foot might render a man useless for general military service, and yet for civilian purposes be of trifling import. The same would apply to many minor disabilities that increase with age. No previous data had given any idea of the extent of age changes in efficiency, though it was well known that the period of maximum efficiency in active games was the ages under thirty. It is therefore not surprising that the numbers fit for severe strain should fall off after that age or that relatively few over forty should be fit for effective military service. There is no reason to think that this is in any way a new phenomenon associated with urbanisation, or that a similar census in past centuries would have yielded any better results; indeed, data on health to be submitted on subsequent pages suggest that larger numbers of fit individuals at the higher ages exist now than in any past time. Another and more serious criticism of this report as an accurate survey of the whole state of the population of Britain rests on the fact that it was only undertaken after some years of war, when the physical pick of the nation had already voluntarily enlisted.

The more valuable data are contained in the records of some 260,000 youths born in 1900, about two-thirds of the total number attaining the age of eighteen in 1918, the proportion in their case being (in round numbers)[3] :—

Grade I.	..	65 per cent.
Grades II. & III.		30 per cent.
Grade IV.	..	5 per cent.

[1] *Report, Ministry of National Service*, vol. i., p. 4.
[2] *Ibid.* p. 109. [3] *Ibid.* p. 22.

These figures are nearer to expectations, although unsatisfactory for those who aim at 100 per cent. efficiency.

The proportions of Grade I. varied from 80-85 per cent. in rural areas, over 75 per cent. in mining areas, 72 per cent. in the suburbs around London, down to 49 per cent. in the crowded industrial areas of Lancashire. Some of the Scottish returns in particular indicate the price of urbanisation, at the ages of eighteen to twenty-one.[4]

—	Rural Agriculturists	Miners	Metal Workers	Small Towns	City
Grade I.	85·7	80·6	86·2	72·7	63
,, II.	7·9	9·3	8·2	13·2	17
,, III.	4·4	7·2	2·9	9·6	12
,, IV.	2·0	2·9	2·6	4·4	7

There is nothing in these figures to suggest that the British people have degenerated more than other nations. The German pre-war figures[5] showed 72 per cent. fit or prospectively fit for service and 28 per cent. less fit or unfit for service, with the same contrast between the rural and urban, the agricultural and the textile areas, as is noted in Britain; while the United States rejected 21 per cent. of their draft of men from twenty-one to thirty years of age.[6] In the latter country the higher proportion of rejections were from the urbanised and more industrial States, and the lowest from the more rural and sparsely populated areas of the West.

In general it may be noted that many of the causes of low grading at all ages were defects which would readily yield to treatment in their initial stages, and that great advantage would arise from the establishment of a social tradition in favour of early treatment, and in particular against septic mouths and uncared-for teeth. The younger members of the community are greatly in advance in these respects, and it is clear that the school, and its ancillary accompaniments, must now be reckoned among the most powerful of public health agencies.

Actual data on stature are very sparse in the reports of the recruiting boards; the figures are below those of the British Association Committee taken as a whole, but differ little if at all in those areas in which corresponding classes of the community can be compared, while the relation between physique and occupation is of the same order in the two reports. The Ministry returns show that a large number of the adult male population examined as conscripts in 1918 had statures between 64 and 67 inches, but the average figure obtained has little significance as an index of the whole pre-war population, since a large proportion of the tall stock had already enlisted. The returns from the United States[7] show that the average stature of the members of their draft who had been born in Britain was Scottish 67·9, English 67·7, a distinctly higher figure, probably to be explained by the greater tendency of the taller stock, the Nordic, to emigrate to fresh fields. The lowest statures quoted by the recruiting

[4] *Ibid.* p. 132.
[5] *Rep. Inter-departmental Committee on Physical Deterioration,* vol. iii., p. 56.
[6] 'Defects found in Drafted Men.' Washington.
[7] *Report of Medical Dept., U.S.A. Army,* vol. xv., Pt. I., p. 106.

boards were found among the casual labourers and the textile workers, who had been subject to bad conditions of environment.

The returns from the School Medical Service show that stature is on the whole greater in England and Wales to the south of a line drawn from the Severn to the Wash, with an extension northward to include Lincolnshire and the East Riding of Yorkshire; in addition, scattered areas containing many tall children occur in Westmoreland, on the coast of Cumberland, in the far north of Lancashire, in the hilly districts of Staffordshire and in Merioneth. This line of demarcation clearly marks off the industrial from the rural districts, though it also largely coincides with areas of former Saxon, Danish and Norwegian occupation. The children in factory towns and mining areas are in general definitely shorter than those in rural districts. Arthur Greenwood,[8] considering the returns from a large number of education authorities, found that the results could be expressed in terms of those for all England and Wales with the following results:—

All England and Wales	100
Rural parts of County Areas	102·4
Urban parts of County Areas	100·5
London	99·6
Manufacturing Towns:	
Glamorgan and Monmouth (Coal and Iron Towns)	98·5
Yorkshire Woollen Towns	98·1
Lancashire Cotton Towns	98·0
Staffordshire Pottery and Hardware Towns	98·0
Durham and North-East Coast (Coal and Iron)	96·6

These findings agree closely with those of the recruiting boards, and a comparison of the two shows that the inferiority in the textile towns becomes more noticeable after the school age. In London[9] the physique is best on the whole in the suburban areas on the higher ground, and is worst in the poorer districts to be found in the central areas, along the Thames flats and in the valleys of the small streams that once flowed across the site of the present county. In Scotland the best physique is to be found in the rural areas, except in the Western highlands and islands where environmental factors other than urbanisation have tended to stunt growth and the racial type differs. As in England, industrial districts are below the average.

The best physique is found in the great public schools, then in order come the secondary schools, the trade schools and the ordinary elementary schools; these correspond pretty well to the leisured and professional, the commercial, the artisan, and the factory and labouring classes, respectively. The stature of the children from the better-class schools, many of whom present Nordic traits and all of whom have been brought up in a favourable environment, is equal to any in the world. The general average for all types of schools is, however, below that of the children of British descent in the Dominion or the Commonwealth. The advantage of the latter supports the opinion that the emigrant stocks from Britain contained a large proportion of Nordic elements, and also suggests that the children flourish under the new environment.

[8] Greenwood, *Health and Physique of School Children*, pp. 27-28, and Appendix A.
[9] *L.C.C. Report of Medical Officer (Education)*, 1910, pp. 131–133.

Even the worst estimates of the present-day physique, when compared with such records as exist of the former inhabitants of the British Isles, afford little evidence of a deterioration of stature in members of a particular racial type, but rather of a change in their relative proportion in the total population. In neolithic times, so far as can be gleaned from skeletal remains, the average stature of adult males was about 63 inches with a few taller individuals interspersed, who were perhaps of the ruling caste; the Saxons averaged about 66 inches, the Norwegians and Danes were a little taller. The stocks in each district remained in comparative isolation until the advent of roads and railways and the demand for labour in new areas caused a greater degree of intermixture. Even now, rural areas which had originally a predominant Nordic occupation contain a taller and fairer population; in the cities the degree of intermixture has proceeded to such an extent that there is relatively little relation between stature and hair colour. Throughout the mediæval period, stature remained little affected so far as can be judged from clothes, implements and armour, which would suit the larger number of the present-day people and would indeed be too small for the better built. In the eighteenth century there were many recruits whose stature was only about 63 inches.

Records of children of Lancashire operative and labouring classes, taken in the second quarter of the nineteenth century, when compared with similar figures at the present day show little change until the last few years. Since the initiation of the School Medical Service, it has become evident that a gradual improvement is in progress. In London elementary schools there has been a gain of a full half-inch in stature since 1904, while in the public schools average gains of an inch or more are recorded. The changes in weight are even more general and significant. It is noteworthy that the average weight of the crews in the Oxford and Cambridge boat race, who were always chosen from the pick of the undergraduates, has increased nearly a stone in the last sixty years.

Comparisons which have been made between children who have suffered from illnesses and those who have had none of importance, show the greater stature of the latter class and indicate one of the ways in which urbanisation exerts malign effects and also the advantages of care in childhood. Many children fail to attain their full stature on account of morbid factors which may act on the growing bones directly, as in rickets, or indirectly through malnutrition resulting from infectious ailments, catarrhs or actual privation. The predominant factor in the determination of stature is of course heredity, but where the soil and climate are unpropitious and poverty prevails the physique of all the inhabitants is depressed irrespective of their racial type. Collignon and others have shown that those removed from such districts in early life recover their normal stature, while those brought into the unfavourable surroundings are proportionately dwarfed.

Taking a more general survey, the health of a people under varying conditions may be measured by the variation in the duration of life as to which data are available for recent years and to some extent for the past. The duration of human life appears to have steadily increased from the earliest times. So far as can be judged from skeletal relics, early man did not live much beyond early adult life, though some individuals, such as the old man of Cromagnon, attained to old age. The words of the Psalmist

suggest that in his time the duration of life of those who survived the vicissitudes of infancy and early adult life was much the same as at the present day. The great gain has been that more now live to middle age or beyond. Macdonell and Pearson analysed the data on mummy cases from the time of the Roman occupation of Egypt [10] and the 'Corpus Inscriptionum Latinarum' of the Berlin Academy,[11] which gives the age at death of some thousands of Roman citizens who had lived either in the City of Rome or the provinces such as Africa, at the early part of the Christian era, and were able to construct rough life tables indicating the probable expectation of life at different ages. These may be compared with tables constructed by Halley on the data in the bills of mortality of seventeenth-century Breslau, by Milne for eighteenth-century Carlisle,[12] and with those constructed on modern census and registration data.

AVERAGE EXPECTATION OF LIFE FOR EACH PERSON LIVING AT THE BEGINNING OF THE AGE INTERVAL, IN YEARS.

Place and period	Roman Egypt	Imperial Rome	Roman Africa	Breslau 17 Cent.	Carlisle 18 Cent.	London[13] 1920-1922
Age						
0–	?	?22	??47	33	39	56
5–	31	24	45	41	51	59
15–	23	22	38	37	45	51
25–	23	20	34	30	38	42
45–	16	19	25	19	25	26
65–	10	12	15	10	12	12
85–	6	8	11	4	4	4

The results shew such an increase in the expectation of life at the earlier ages as to emphasise Karl Pearson's comment on the Egyptian data: 'either man must have grown remarkably fitter to his environment or else he must have fitted his environment immeasurably better to himself.' Even in the early days, however, the diasdvantages of the more urban surroundings are evident in the lower span of life in the Imperial City as compared with the Roman provinces. That a similar difference existed in the British Isles is certain, though from lack of data detailed comparison is impracticable until the last century.

The expectation of life varies from class to class much as does physique, being greater for the professional classes than for the agriculturist, for the agriculturist than for the miner, while the latter in turn is a better life than the tailor or the textile worker. From life tables based on the mortality experience of the years 1911-12, the expectation of life appears to be greater in the South than the North of England and to vary in each area with the degree of industrialism and urbanisation. It also seems when the data as to numbers of survivors are plotted on a map that there is a greater expectation in those areas which, at any rate until recent times, were occupied by a predominantly Nordic population.

10 Pearson, K., *Biometrika*, vol. i., pp. 261-264.
11 Macdonell, W. R., *Biometrika*, vol. ix., pp. 366-380.
12 Pearl, R., *Biology of Death*, pp. 79-101.
13 Unpublished data by courtesy of B. Spear.

Expectation of Life in England and Wales, 1911-1912.[14]

MALES.

Age	Area			
	London	County Boroughs	Urban Districts	Rural Districts
0·	49·5	47·5	51·9	56·3
5·	55·3	54·7	57·6	60·2
15·	46·8	46·3	49·0	51·4
45·	22·5	22·2	24·1	26·3
65·	10·5	10·0	10·8	11·9
85·	3·6	3·5	3·6	3·6

General health has often to be estimated from the records of mortality, though it must be remembered that morbidity is much greater than mortality and that the after effects of injury or disease may long affect the physique of the sufferer. Lethal agencies are sometimes local, sometimes widespread in their action, and may at times exert a selective action on the population affected. Tertullian long ago maintained that earthquakes and wars, famine and pestilence have to be regarded as a means of pruning the luxuriance of the human race. These vary greatly in their mode of action and powers of selection. Earthquakes need not be considered so far as England is concerned during the historic period.

War in early culture might occasionally wipe out a whole population, but more often the skilful and strong survived; in modern war the selection favours those whose physique does not permit of active military service and is thus opposite in tendency. This indeed has been offered as a partial explanation of the poorer physique recorded of those French conscripts who had been born during the wars at the beginning of the last century, when the fittest of the adult male population were absent or killed. War acts more lethally through the social disorganisation, and the consequent famine and disease, which follow in its train, than through any casualties in the field; from these direct experiences on its own soil, England had been singularly free since the Norman period. Philip de Comines remarked 'England has this peculiar grace that neither the country, nor the people, nor the houses are wasted or demolished; but the calamities fall only on the soldiers and especially on the nobility.'[15] The wider effects of war were only felt, and then but locally, in the campaigns of the Stuart reigns, though there was great suffering earlier in the forays on the marches of Wales and Scotland. Thanks perhaps to the great demand for labour and to the separation allowances, as well as to the seat of action being abroad, the recent war has exerted no obvious harmful effects. The children have been well nourished and there was no great increase of defective children, such as had been anticipated by some, even in the areas most exposed to air raids. There was, it is true, an increase in the number of children who were troublesome and educationally

[14] *Supplement to 75th Annual Report of Registrar-General of England and Wales*, Part II., p. 34.

[15] Philip de Comines ed. Godefroy, *Mémoires, III.*, p. 155. Quoted by L. Creighton, *Hist. of Epidemics in Britain*, vol. i., p. 224.

backward, but on examination it was clearly seen that these features were not due to innate characters but to truancy and lack of discipline during the absence of their fathers.

Famine took its toll in Western Europe in the mediæval period, but England was the country in which the mass of the people soonest attained to fairly constant comfort. A poem, attributed to Henry of Huntingdon, contains the stanza:

> 'Anglia terra ferax et fertilis angulus orbis
>
> . . . .
>
> Externas gentes consumptis rebus egentes
> Quando fames laedit, recreat et reficit.' [16] [17]

This was a great contrast to France, which repeatedly suffered from long years of famine, but England certainly had occasional periods of scarcity at long intervals. Creighton,[18] it is true, draws attention to a mediæval saying 'Tres plagae tribus regionibus appropriari solent, Anglorum fames, Gallorum ignis, Normannorum lepra'; probably, however, the English were so used to good feeding that they indulged in the national habit of grumbling over a scarcity that elsewhere would have been taken as a matter of course. The 'Vision of Piers Ploughman' [19] seems to bear this out:

> 'And tho wolde wastour nouzt werche, but wandren aboute
> Ne no begger ete bred that benes Inne were,
> But of coket or clerematyn or eles of clene whete:
> Ne none halpeny ale in none wise drinke,
> But of the best and the brounest that in burghe is to selle.'

While Harrison in his 'Description of Britain' [20] quotes a Spaniard in Queen Mary's day as saying 'These English have their houses made of sticks and dirt, but they fare commonly as well as the king.' In modern times the only state of affairs which could be compared with events in the mediæval period is the Irish potato famine, in which actual starvation was accompanied, as of old, by outbreaks of fever and an abandonment of effort from sheer despair. In general any morbid influences on nutrition arose rather from a seasonal scarcity of certain essential articles of diet than from famine in the ordinary acceptation of the term.

Disease, throughout the historic period, must have been the most lethal of all the morbid agencies. There is nothing to suggest that there are important diseases to-day from which our ancestors were free, with the possible exception of syphilis, which is first recorded at the very end of the mediæval period. Anglo-Saxon leechdoms reveal that there were then, as now, cancer and consumption, gout and stone, the falling sickness and St. Vitus' dance, fevers, catarrhs and rheums. Even congenital defects were noted, Giraldus Cambrensis [21] in his 'Topographia Hiberniae' referring to the many individuals who were born blind, lame, maimed or having some

[16] *De praerogativis Angliae.* Quoted by Higden, *Polychronicon*, Rolls ed., ii., 18.
[17] Creighton, *l.c.*, vol. i., p. 8.
[18] *L.c.* vol. i., p. 52, with reference to Fuchs *Das heilige Feuer im Mittelalter.* Hecker's *Annalen*, vol. 28, p.1. This latter cites *Alberici Chronic.*, Bouquet, xii. 690.
[19] William Langland, *Piers the Plowman*, passus vi., l. 304-308. Skeat's ed., p. 77.
[20] William Harrison, *Elizabethan England*, the Scott Library edition, p. 114.
[21] Rolls ed., vol. v., p. 21.

natural defect. On the other hand, certain of the scourges of our ancestors have practically disappeared, especially some of the infectious diseases. Leprosy and plague long ago ceased their ravages, typhus and famine fever vanished, save for isolated cases in later Victorian times, enteric fever has lessened nearly to the vanishing point, and even infantile diarrhœa is becoming less year by year. Most, if not all, of these diseases may be communicated by animal agencies, either by direct inoculation from bites or by secondary contamination. The louse, the bug and the flea, common until recent years, are succumbing to the newer tradition and meaning of cleanliness which has followed universal education, the medical inspection of scholars, and the action of public health authorities; the fly, an indirect agent, is being eliminated by improved sanitation, and the gradual disappearance of horse transport in our cities. As the changes proceed more rapidly in the towns the approximation of their health conditions to those in rural areas follows.

Epidemic diseases have always attracted more notice from the historian owing to the wide extent of the resulting evils, so that much is written concerning the plague, the sweat, gaol fever and smallpox compared with more common disorders of life. Some of these have appeared in earlier days to exert some selective influence, though this selection depended rather on the mode of transmission of the disorder. Any disease transmitted, whether by vermin or from case to case, would be more prevalent under conditions in which the population were closely massed, and at periods or under conditions in which either the facilities or the sentiment for cleanliness were lacking. The plague, save in its first pandemic outbursts as the 'Black Death,' was mainly a disease of the poorer classes in the towns, in each epidemic affecting especially the worst housed, worst fed and least cleanly. Sporadic outbursts in rural areas followed the introduction of infection from without, as was well recognised by villagers who forcibly endeavoured to prevent the entrance of travellers from affected areas. Gradual changes in habits and domestic furnishing which reduced the breeding-places of rats and fleas were followed by the extinction of the plague. The sweat, it was noted in Tudor times, differed in its incidence;[22] Kock said of the 1529 pandemic 'the poor people and those living in cellars and garrets were free from sickness,' while Renner noted 'it went most among the rich people.' This tradition, or a continuance of similar phenomena, must have remained, for we find in 'Measure for Measure'[23] Mistress Overdone says, 'Thus what with the war, what with the sweat, and what with the gallows, I am custom shrunk.' It was noted over a long period that whereas typhus, gaol fever, and the like were always present among the poorer classes, the greater mortality followed outbreaks among healthier individuals, who had lived an open life, such as soldiers brought back to barracks after a campaign in the field, sturdy felons newly flung into gaol, or, as in the Irish famines, magistrates and relief workers whose duty carried them into the haunts of the disease. In the case of the 'Black Assizes,' when judges and jurors succumbed but the prisoners escaped lightly, the phenomenon was ascribed to the latter being inured to

[22] Creighton, *l.c.*, p. 268, with reference to Gruner, *Scriptores de sudore Anglico superstites*, p. 444-448.

[23] Act i., Sc. 2.

the stenches of the cells, though the modern explanation would suggest that they might have acquired immunity from previous and possibly slight attacks. It has been argued that such epidemic diseases served a useful purpose in that they removed weaklings, but the type selected by this test of relative immunity to typhus or gaol fever is not one to be commended on account of its mental or physical traits. The general statement is however open to doubt; Ballard [24] reporting on the Leicester outbreak of infantile diarrhœa in 1881 stated, 'Our experience of these epidemics by no means supports an opinion commonly held that a summer diarrhœa makes its first fatal swoop upon the weakliest children.' While the alleged benefits to the community of this mortality are neither uniform nor undoubted, the evil effects of infectious disease are very real, for it is a matter of common observation that the effect of these illnesses, especially in children, is to lower the vitality and reduce the physique sometimes even permanently.

In endeavouring to trace the changes in mortality in England it will be noted that in early days all is expressed in vague terms, *e.g.* that in the days of the Black Death 'a fifth part of the men, women and children in all England were consigned to the grave'; [25] occasionally a local chronicle records of certain years that the burials greatly outnumbered the christenings, but definite information only begins with the London bills of mortality in late Tudor times. From them we learn that in the liberties of the City, within and without the walls during the great plague years, the mortality ranged from 200 to over 400 per 1,000 living, and that in healthy years, which were few, the rate was some 60 per 1,000. The subsequent history of London is one of steady fall of mortality, though the greatest change has occurred in our own lifetime. In the latter part of the seventeenth century the rate was 80 per 1,000 living, in the eighteenth century it was 50, by the middle of the nineteenth century it was only 25, and since 1875 it has fallen rapidly to the present rate of 11-12 per 1,000. Some part of this change is due to variations in the age and sex constitution of the population at risk, but even when all corrections for this have been made, the mortality rate in England and Wales has fallen over a third since the beginning of registration in 1838.

A great part of this reduction has been in the infant mortality, which is perhaps the most important from the standpoint of potential parenthood. This mortality in early years was very high, thus in 1754 the deaths in London of children under two years of age were 45 per cent. of the deaths at all ages. Since the period of registration the infant mortality oscillated around 160 per 1,000 until 1900, since when it has fallen to 60 per 1,000 in 1923. The great part of the fall has been in deaths due to infectious diseases and diarrhoea; there has been little or no change in the rates from congenital defects or developmental disorders which have remained relatively unchanged in all classes of the community, so that this lethal selection against the naturally unfit remains as rigid as ever. The fall in the mortality rate has been ascribed to various features: cleaner milk, fewer flies, the disappearance of the old feeding-bottle, and it seems to be most certainly connected with increased skill in maternal care. Thus

[24] Ballard, *Report of Local Government Board*, 1889, p. 43.
[25] *Eulogium Historiarum*, Rolls ser., No. 9, III., 213.

it arises that the better spaced out the children are, the more survive. It is also significant that the change should have come about in the second generation of universal elementary education, suggesting the possibility that when the influence both of grandmother and mother is exerted in the direction of the sentiment for cleanliness inculcated in the school, the child reaps the benefit.

The mortality in the early years of life is greater in the cities than in the small towns and in these than in the rural areas; it is greater in the north than in the south for all classes of the community, but it must be noted that with the great fall in the present century the gap between urban and rural areas has been closing. This again suggests that education and a higher standard of personal hygiene are important factors, for the country is always more conservative in its actions and beliefs. In the same way, comparing the social classes, the death rate is lowest in the upper classes, particularly among the children of professional men, and the agriculturists, but highest among the unskilled workers and the miners. This indicates that the influence of custom as well as the direct effects of urbanisation may be factors to be considered.

Special causes of morbidity are to be found in each of the main classes of workers. The mortality of the infants of agricultural labourers is below that of those of any other class of manual workers, not only as far as diarrhœal diseases are concerned—here, perhaps, they have better chances of obtaining fresh milk—but also from measles, tuberculosis and respiratory diseases generally. Some of the difference may be due to the rural child, on the average, being older than the townschild at the time he is attacked by infections; for, whereas infantile infections spread through towns about every second year, in the country districts there may be an interval of five years between periods of epidemic prevalence. The infant mortality among textile workers is especially due to diarrhoea,[26] which may be ascribed in many instances to artificial feeding during the mother's absence at the mills. The children of this class also die notably from congenital malformation and prematurity, which might naturally have been attributed to the mothers working until a late stage of pregnancy, were it not that the mortality from these causes is even higher among the children of miners, whose women seldom work outside their own homes. The general infant mortality among the miners is higher even than among the unskilled and casual labourers in the towns, and if diarrhœa, gastritis and convulsions be taken together, their death rate from these causes is the highest of any class. In the Glamorganshire coal-fields the standardised child mortality in 1911 was 217 per 1,000 births for miners, and 176 for the rest of the workers in the area.[27] This may be due to improper feeding, to insanitary conditions, or possibly expresses some difference in traditional methods of infant care; though it should be noted that as the miners have the larger families there must be less individual attention available for each child.

On the whole the evidence goes to show that morbidity, and especially infant morbidity, is closely associated with the aggregation of population,

[26] Various Annual Reports of Registrar-General, England and Wales, and especially Supplement to 75th Annual Report.

[27] *Census of England and Wales*, 1911, vol. xiii., pt. ii., table li.

but that in recent years improved standards of social or individual hygiene and comfort have done much to neutralise specific causes of ill-health. It may also be taken as proven that such ill-health is the greatest cause of stunting of physique. As in the past the countryside has been freer from these morbid influences, the country-man has been the physical superior of the townsman, comparing class with class.

There are three main ways in which the growth of towns and of the industrial system has prejudiced the health and thus the physique of the nation: adverse conditions of work which had little influence prior to the eighteenth century, unhygienic housing and bad feeding, which in varied ways have exerted their effects throughout a large part of human history. Some of these would be peculiar to the town, others would fall indifferently on town and country, and on all social classes save perhaps the very wealthiest, though even they could not entirely escape. The contrast is less vivid than would appear at first sight: the country child can get fresher food, it is true, but less of it perhaps, owing to the lower wages of his parents, though he often eats margarine, the butter being sold in the towns; he gets fresher air outside but not indoors, since the country cottage may be as dark, ill-ventilated and overcrowded as any in a city court.

The greatest change in the conditions of work was the rise of the factory, involving long confinement in monotonously ventilated rooms, as opposed to work in the open at the door of the home. Industrial centres may have been established in Roman times, but thence after for a thousand years and more they did not exist, and agriculture was the only important industry. The only factories were the local wind- or water-mills; there were local industries in cloth, linen or metals, but the great centres of to-day were non-existent.

The early factory was an extension of the home. Ure said: 'The workshop of the weaver was a rural cottage, from which when he was tired of sedentary labour he could sally forth into his little garden and with spade or hoe tend its culinary productions.'[28] Woollen weavers practised agriculture as a by-employment as late as the early part of the last century. The introduction of water and steam driven machinery aggregated the populations into the northern towns which arose near the sources of the power, and put a premium on the employment of children who could then do work which formerly required a man's strength. When local supplies ran short, children were procured from workhouses, even from as far off as London. Hunt, in his 'Political History of England,'[29] says: 'From little more than infancy they laboured for long hours, thirteen or more a day, in rooms badly ventilated and injurious to health. They were half starved and cruelly punished. Such of them as survived the prolonged misery and torture of their early days, grew up more or less stunted and deformed men and women, physically unfit for parentage, morally debased, ignorant and brutalised by ill-treatment.' The mills were hot beds of 'putrid' fever, and the morbidity and mortality rates were appalling. In recent years the general hygiene of the worker, together with the removal of industrial risks, has made enormous strides, the result being apparent in the falling death rate and the healthier children.

[28] Ure, *Cotton Manufacture of Great Britain.*
[29] Hunt, *Political History of England*, vol. x.

So far as housing is concerned, in early days the English dwelt scattered through woods and marshes; in mediæval times they began to flock to the towns in which the sanitary conditions were bad; though regulations have existed even from Plantagenet days for the abatement of nuisances,[30] *e.g.* the prohibition of the erection of pigsties in the streets of London. In the late mediæval period there were narrow streets with overhanging upper stories so that light rarely entered the lower apartments.[31] Indoors, even in the great houses, the floors were covered with rushes piled, according to Erasmus,[32] the new on the old for twenty years without clearance: an excellent breeding-ground for vermin. Sanitation was perhaps a little, but not much, better by Stuart times; and, 'whatever sanitary gains may have accrued from the destruction of the City in the Fire, London in the late seventeenth century was an ill-conditioned place of residence, with hardly the rudiments of sewerage or water supply, and no systematic removal of refuse.'[33] In many years the burials out-numbered the baptisms and the town fed on the country. In Hanoverian times matters, if anything, deteriorated owing to the most unhygienic window tax; this, however, affected the country perhaps as much as the towns, for Howard[34] refers to 'farmhouses where the labourers are lodged in rooms that have no light or fresh air; which may be a cause of our peasants not having the ruddy complexions one used to see so common thirty years ago.' During the industrial revolution the aggregation of houses and the pollution of the air greatly increased and produced their well-known evils, though the sanitation of the individual houses was, in some respects, no worse than before. London lost its evil pre-eminence in the matter of mortality which was transferred to the manufacturing towns of the north, in which diarrhœa attacked the infants, and fevers of all kinds their elders. In the late Victorian period conditions steadily improved, although in remoter districts matters change so slowly that some of the present-day crofters' huts in the Outer Hebrides closely resemble the habitations of neolithic man.[35]

The third factor, food and its assimilation, is more closely associated with the foregoing than is usually realised. Leonard Hill[36] has shown that sedentary occupations in still warm atmospheres have the effect of lowering the general metabolism and of reducing the desire for food, thus producing a similar effect to actual privation and affecting even the well-paid worker. Acting through long periods during the growing time of life, such factors whenever they arise may stunt growth as well as predispose to illness. McCarrison[37] has indicated that the adult worker and even more the adolescent, need, no less than the growing child, a supply of food rich in vitamines, and balanced in its organic and inorganic

[30] *Memorials of London* (H. T. Riley), p. 339, *et seq.*

[31] W. White, *Phil. Trans.*, lxxii., p. 35.

[32] *D. Erasmi Epistolae*, lib. xxii., epist. 12, London, 1642.

[33] John Simon, *English Sanitary Institutions*, p. 106.

[34] John Howard, *State of the Prisons*, p. 10.

[35] Carnegie United Kingdom Trust. Report on *The Physical Welfare of Mothers and Children*, vol. iii., Scotland. Plates XIII., XIV., and XV.

[36] L. E. Hill, *Medical Research Committee, Special Report Series*, No. 32.

[37] *Medical Research Committee, Special Report Series*, No. 38; also *B. Med. Jour.* Feb. 21, 1920.

components; without this they lack both vitality and resistance. The foods required, eggs, butter, animal fats and fresh vegetables, are very expensive, but are not replaceable by the cheaper vegetable oils and lard. Many dietaries which appear satisfactory on a mere caloric basis prove failures owing to the lack of these vital elements. The industrial worker is doubly handicapped; he not only loses his appetite and takes scarcely enough to provide the necessary energy for his work, but, too often, he takes even that in the form of margarines and canned foods which do not supply adequate vitamines. There is reason to think that the war-time rationing of foods and control of prices was to the benefit of the growing child of the elementary-school class in that it secured a more equable distribution of the essentials at a rate which was within the range of the family exchequer of a very large number. This helps to explain the undoubted improvement of children's health and physique during a period in which disaster might confidently have been anticipated. If, as is probable, physique suffered with the concentration of the population in the industrial areas, no small part may have been played by the confinement in a relaxing atmosphere and the substitution of inert for live foods. The worker who emigrates to more rural surroundings reverses these conditions and, if young enough, recovers part of his lost physique, and in any case his children, not being handicapped, fulfil their true potentialities. With feeding as with housing, though the industrial age brought its own defects, yet the contemporaneous increase of civilisation provided the remedy for some of the previous evils, such as those arising from imperfect methods of food preservation.

Gilbert White wrote in 1778[38]: 'Three or four centuries ago before there were any enclosures, sown grasses, field turnips or carrots, or hay, all the cattle which had grown fat in summer and which were not killed for winter use were turned out soon after Michaelmas to shift for themselves through the dead months, so that no fresh meat could be had in winter or spring.' The curing at the best was very imperfect, and the diet of the poorer classes would be the semi-putrid sides of bacon, mutton or beef. Indeed, it was enacted that such should be given to the outcast by the Scottish Parliament at Scone in 1380.[39] 'Gif ony man brings to the market corrupt swine or salmond to be sauld, they sall be taken by the baillie and incontinent without any questions sall be sent to the lepper folke; and gif there be no lepper folke, they sall be destroyed alluterlie.' Such continual winter sufferings must have worked harm, seeing that it was not a matter of an occasional meal but a steady regimen. No wonder an Aberdeen physician wrote of the effects: 'As we see dailie the pure man subject to sic calamitie nor the potent, quha are constrynitt be povertie to eitt evill and corrupte meittis, and diseis is contracit, heir of us callit pandemiall.'[40]

Toward the end of the eighteenth century the long-standing defects of food and housing were in full force, and their influence was accentuated by the coming of industrialism and the massing of people in towns. Thus disease from bad feeding and insanitary surroundings was the bane of

[38] *Natural History of Selborne.* Letter to Barrington, Jan. 1778.
[39] *Acts of Robert III.*, *Regiam Majestatem*, p. 414. Quoted by Creighton, *l.c.*, p. 113.
[40] Gilbert Skene, *Treatise on Plague*, Bannatyne Club ed., p. 6.

the metropolis and of the larger cities. Sir W. Fordyce[41] could write: 'I speak within the bounds of truth when I assert that, judging from the cases brought to my notice since 1750, there must be very near twenty thousand children in London, Westminster and the suburbs ill at this moment with the hectic fever, attended with tun bellies, swelled wrists or ankles or crooked limbs, owing to the impure air they breathe, the improper food on which they live, or the improper manner in which their fond parents bring them up.' Within our own memory disease such as is described by Fordyce has become unknown; rickets in mild form still reduces stature, but severe deformities are rare in London and the South, though as yet to be found, albeit in lessened numbers, in the industrial cities of the North. The evils were checked in part by the various Factory and Public Health Acts and by improved sanitation which gradually came into force, while other causes of malnutrition, such as late hours, lack of sleep, uncleanliness, and premature heavy work, have more recently given way before the force of the higher standard of civilisation and of personal well-being.

Modern medical inspection and treatment are fast counteracting the chief causes depressing the health and physique of the children, and are also dealing with contributory secondary factors, such as defective teeth and other foci of chronic sepsis, verminous conditions and unsuitable clothing. No one who compares photographs of present-day children with their predecessors of the 'seventies can doubt the change. It is significant that the town is now gaining over the country and that London children are now second to none. The treatment schemes did not come into force until just before the war, and affected almost exclusively children who did not reach military age in time to appear before recruiting boards, so that the benefits of the system could not be brought out in the Report of the Ministry of National Service. In this direction the future seems secure.

There remains the gap between the school and adult life. An experienced Scottish recruiting board reported a falling off during adolescence both in the agricultural and the industrial classes.[42] In the former there are 'the evils of the bothy system, with its lack of home comforts, and the tendency to live on canned food'; in the latter 'the boy goes to the factory at fourteen, by sixteen he is earning full wages, indulging in all kinds of excesses, not having his due share of sleep and living on unwholesome foods.' The young artisan, apprenticed to his trade, has far more favourable conditions; 'he does not realise his full wage-earning capacity so early, his home is better, his social conditions more equable, he has not the same opportunities for excesses and lives a more physiological life.' The general impression of the recruiting reports was that the most critical period in determining the physical standard of manhood was the age from fourteen to eighteen. With any extension of facilities for apprenticeship or trade instruction, with opportunities for the further treatment of ailments, even though these be of a voluntary character, much would be gained. Moreover—since the use made of these facilities would depend

[41] W. Fordyce, *A new Enquiry into the Causes, Symptoms and Cure of Putrid and Inflammatory Fever*, London, 1773, p. 207.

[42] *Report, Ministry of National Service*, vol. i., p. 138.

on the mentality and character of the individual—the youth with the best mind and good will should gain the advantage and be favoured in his prospects of a successful marriage, through which he could transmit these qualities to further generations.

Turning to the genetic aspects of the subject, it is clear that the future of the nation depends on the interaction of two somewhat opposed processes, reproductive and lethal selection. Fecundity is a heritable trait, and parents who themselves are members of large families tend to produce many offspring who, in their turn, are similarly prolific. Lethal selection, on the other hand, counteracts this tendency in that the demands of a large family reduce the chances of the parents protecting themselves or their offspring, since the available care has to be distributed over a larger number. It will be noted that the shorter the intervals between successive births, the higher is the rate of infant and child mortality.

The materials for any investigation into changes in density of population are very scanty until the decennial censuses can be consulted. While there are reasons to think the country was by no means sparsely occupied in early days, there are no, even approximate, estimates until the fourteenth century, when the population of England and Wales is believed to have been about three million. There was a slow rise to six and a half at the middle of the eighteenth century, thence on a growth to nearly nine million at the first census of 1801, sixteen million in 1841, and twenty-six in 1881. After this the rate was retarded, and in 1921 the population was approximately thirty-eight million. The period of rapid growth coincided with the industrial development of the early nineteenth century, the slowing down with the rise of competition from abroad.

It is important to note that the increase of population was not uniformly distributed, either as to district, class or occupation. In the earlier days the greatest density of population was, in the main, south of the line from the Severn to the Wash but extending up to Lincolnshire and the East Riding, and the predominant occupation was agriculture. A change began with the great development of pasture and the relative abandonment of arable land which reached its height in early Tudor times, when Hythloday could be represented in 'Utopia' as saying: 'Your shepe that were wont to be so meke and tame and so small eaters, now, as I heare saye, be become so great devowerers and so wylde, that they eate up, and swallow downe the very men themselfes. They consume, destroye and devoure whole fieldes, howses and cities.'[43] This process reduced the numbers, especially in the eastern counties and the southern midlands. Some two centuries later the rise of industrialism in northern areas adjacent to water power and coal led to a great increase of numbers in marshy and moorland districts which had formed the refuge of a scanty and often pre-Nordic population.

The areas of highest fertility to-day are the northern counties and Wales, while the lowest are found south of the line from the Severn to the Wash[44]; probably the difference is mainly due to social and industrial rather than to racial factors. The rural population is the more fertile;

[43] Thomas More, *Utopia*, Bohn's ed., bk. i., p. 38.
[44] *Census of England and Wales*, vol. xiii., pt. ii.

even in cities the country-born have larger families than the true urban population. The higher rate of child mortality in the towns increases this difference, so that there is no part of England where the rural areas are not more effectively fertile than the small towns and these than the county boroughs. Their greater numbers, however, ensure that the urban population makes the bigger actual contribution to future generations. The rate of increase of the population is dependent upon the fertility, the age of marriage, the proportion of married individuals and the death rate, especially in early life. Of these there is no reason to suppose fecundity as opposed to fertility has undergone any change, but the other factors have shown marked differences both from time to time and from one social class to another.

Little seems to be known of the age of marriage or the extent to which any class remained celibate in early days; there were certainly restrictions on the marriage of serfs, while in the later mediæval period the craft guilds opposed the marriage of apprentices, and until the nineteenth century subordinates in industries and handicrafts usually lived in and did not marry until they became master men. The less skilled workers soon attain to their maximum earning capacity and marry early, while the office worker and professional man has to wait to establish his position. The agricultural classes and skilled artisans also are noted to marry later than either the unskilled workers, the miners or the factory operatives.

The census of England and Wales for 1911 [45] shows that the highest proportion of married men is to be found among the miners, who are followed at some little distance by the artisans and textile operatives; while the agricultural labourers and the professional classes show the lowest marriage rate of all. The latter figures have a distinctly dysgenic significance which is accentuated by a consideration of the later age of marriage in these classes. Failure to mate is even more marked among the professional women than among the men and has steadily increased decade after decade.

During recent years there has been a decline in fertility, a process which began in the higher classes, who have shown the phenomenon throughout the whole period in which registration data have been available. It is difficult to say what may have been the case in the past, but early genealogies usually record large families though relatively few survivors to maturity, so much so that the population was almost stationary between 1700 and 1750. From the economic standpoint, Pearson, [46] investigating the statistics of various parts of England, has suggested that the fall in the local birth rate became accentuated at certain dates which corresponded with local or general restrictions on the employment of children. Another view would ascribe the decline in fertility to a gradual subordination of the sex instinct with the spread of culture and education. A comparison of the literature of different periods bears witness to a gradual disappearance of the idea that the only career for women was marriage, and that a girl should be reproached as an old maid at twenty. On this basis the decline would have spread from above downwards and would be delayed among certain classes. This factor involves both individual

[45] Vol. xiii., pt. ii.

[46] K. Pearson, *The Scope and Importance to the State of the Science of National Eugenics.*

and group psychology since social traditions and class consciousness as well as personal passion are concerned, which helps to explain the lack of response to the appeals of the enthusiastic eugenist.

That reduction in fertility has been of long standing is strikingly illustrated by Crum's [47] study of the New England genealogies, in which he finds a progressive reduction in the size of the family and an increase in the proportion of childless marriages.

Period	Average size of Family	Percentage of Childless Wives
1750–1799	6·4	1·9
1800–1849	4·9	4·1
1850–1869	3·5	5·9
1870–1879	2·8	8·1

The decline among the professional classes in Britain, even when variations in age and length of marriage are allowed for, is a marked feature of the census of 1911. Of the other classes, miners, agricultural and other labourers have families above the average size, artisans are about the general average, while textile workers and other factory operatives have smaller families. The divergence between the different social classes was less marked in 1850 and reached a maximum in the 'nineties.

The differential death rate, chiefly due to infant mortality, to some extent modifies the initial differences in fertility; while the high fertility of the agriculturist is largely opposed by the low marriage rate and the relative infertility of the upper classes is exaggerated from the same cause. Both total and effective fertility are affected by female occupation, which tends to restrict the number of births, and also to increase the infant mortality owing to the absence of maternal care for a large part of the day. Such occupations are most common in the case of wives of textile operatives, themselves accustomed to factory and mill life from a relatively early age, and among the wives of the labourers in the towns.

The influence of differences in effective fertility in changing the distribution of the population among different social classes can be seen from a comparison of two tables, the first of which gives the percentage of each social class among the married couples, and the second the percentage of these classes among the surviving children from such parents.[48]

Social Class	Distribution per cent.	
	Couples (Parents)	Surviving Children
Upper and Middle .	10·0	7·2
Distributing . .	16·0	14·1
Skilled Artisan . .	24·6	24·8
Mixed Occupations .	17·0	17·6
Unskilled Labourers .	17·1	18·1
Textile Trades . .	3·1	3·1
Miners . . .	8·7	10·7
Agricultural Labourers .	3·5	4·4
	100·0	100·0

[47] Crum, *Quarterly Journal, American Statistical Association*, 1914.
[48] Census of England and Wales, 1911.

This means, to take a concrete example, that the miners who form only 8·7 per cent. of the parent class provide 10·7 per cent. of the surviving children. The unskilled labourers, the mining and the agricultural classes thus appear to be gaining at the expense of the upper and middle and the distributing classes. Miners and agriculturists are usually of good physique, though from the mental standpoint the change is possibly dysgenic.

There appears to be a general impression that the number of defective individuals, particularly of those suffering from mental defect, is greatly increasing. There is little evidence on this point of a comparable nature, but it may be definitely said that in London no such increase has taken place during the last fifteen years. The stocks from which defective individuals come are certainly often prolific, but the infant mortality is high. Indeed, so far as those individuals who are themselves mentally defective are concerned, the figures from institutions indicate death rates from ten to twenty times as great as those of the normal population. The figures regarding the defectives who have been kept under supervision in their own homes indicate rates far above the normal, though perhaps less than those in the institutions to which the worst cases naturally drift. Contrary also to popular belief mentally defective individuals do not mate in nearly as high a proportion as the normal. Out of some 360 defective girls who, while remaining outside an institution, have been under supervision during the past ten years and who are of reproductive age, only eighteen have married and only seventeen have had illegitimate children, a figure which, if regrettably above zero, is not one to cause alarm. Of their children a large proportion appear up to the present to be of normal capacity. There is some reason for thinking that there is a great intermarriage between defective stocks, and that the actual number of such stocks is in reality quite limited.

The London school service has collected information as to the size of the families one member of which has come to notice on account of mental deficiency. The figure will naturally appear higher than one derived from the census returns, since no knowledge exists concerning childless families of the same stocks or of families in which all the children had died. The figures are corrected to show only completed families which have been taken as those where the mother, at the time of the inquiry, had died or had attained the age of forty five, and, for purposes of comparison, similar figures are given for the families of children who had obtained scholarships.

Group	No. of Pregnancies of Mother	No. of Deaths	No. of Surviving Children
Imbeciles and Idiots	6·0	1·7	4·3
Children at Schools for the mentally defective	5·3	·9	4·4
Scholarship holders	4·8	·5	4·3

As the differential death rate continues to act there is reason to think that the defective stock are the less effectively fertile by the time the reproductive age is reached. If it be remembered that the factors act still more severely against those themselves actually defective, the reason why the defective has not overrun the country is evident. Experience in any

children's hospital or infant welfare centre reveals the handicap against the children of the mentally inferior parent.

There remains one important factor bearing on physique—namely, emigration. Since the early part of the seventeenth century the British Isles have sent abroad large numbers of the most efficient of their people, agriculturists and skilled workers of all kinds possessed of just the qualities which the nation demands for its own physical good. Where these have come from somewhat isolated areas the result has been a steady loss of the best, with the consequent replacement in the next generation by the offspring of an undue proportion of the next best. This clearly has a dysgenic effect, and it is often stated that this is the cause of the inferior calibre of the inhabitants of some remote hamlets. This—probably the most serious drain to which the nation has been, and still is, exposed—can only be regarded with equanimity on the ground that England's loss is the gain of the daughter nations. The emigrants have been largely of 'Nordic' and 'Prospector' stocks, seeking a wider scope for their energies, and the result will in the end seriously modify the racial composition of some parts of the British Isles, particularly Scotland. So far as there has been any difference between rural and urban areas it is distinctly the former that have supplied the higher proportion of emigrants. Emigration, indeed, in recent years has been a serious factor in rural depopulation.

Summarising the whole survey I would submit that a pessimistic view of the physical or mental condition of the people of England is unnecessary and unfounded. Stature and weight at least are not less than in the days of the 'Making of England,' of Agincourt or of Waterloo. The great war showed the possession of powers of resistance to physical adversity that have never been equalled, and under a test applied to a proportion of the nation never before approached, while the versatility of inventive powers was demonstrated everywhere. So far as the children are concerned, education is more general and the ladder wider and more used than at any period in our history. The general health of the nation is better and the expectation of life longer than ever before. There are no grounds for thinking the physical conditions of any class are worse than that of corresponding classes at previous epochs, even among those persons and classes on whom the adverse conditions of life associated with urbanisation and industrialism have pressed hardest and have been least opposed. The real increase of the unfit is much less than has been assumed from *a priori* arguments. Reproductive selection which has a tendency to increase the apparently less valuable stocks is opposed by a lethal selection which has not been abolished, while emigration from the eugenic standpoint, though a real disadvantage to England, has been a source of strength to the Empire of Associated Nations. The dysgenic tendencies of industrialism are being successfully opposed by the higher level of general culture and the awakening of a national conscience, but more especially by the more intelligent care for the children of the nation, in which the application of preventive medicine to education is playing no mean part. The Education Acts, if they have not revealed every child as a potential university scholar, have proved the best of Public Health measures; while all available evidence points to the intellectual average being equal to that of any other country. Civilisation may be making greater demands

on its bearers, but their qualities are neither diminishing nor deteriorating and more and more are fitted to shoulder the burden.

A younger country in developing its industries can profit by the experience of the older and secure from the start better hygiene and a more effective education, can watch over its most favourable racial elements, establish a public opinion favourable to the early segregation of degenerate types, and, as Canada is doing, can limit immigration to those fit to become citizens of the great Dominion.

Periodical surveys are necessary to check the changes in the population. Failing more extensive measures these may be effected through the records of the medical inspection of school children, though in these anthropometric data are but scanty. Toronto has long been known for its standard survey, and it is to be hoped that similar data will be collected in all parts of the Dominion. The matter is of great importance, since it is only on the basis of careful physical and mental surveys that legislation directed towards social and racial hygiene could properly be introduced and rightly justified. The lack of such information has been a great handicap to the discussion of such measures in Britain, and has allowed a freer play to pessimistic views.

None the less, despite all forebodings, it may confidently be stated that the mother nation has remained true to herself and deserves now, as of yore, the encomiums of the 'Polychronicon'[49]: 'Engelond ful of pley, fremen well worthy to pley, fre men, fre tonges, hert fre, fre helth al the leden.'

[49] R. Higden, *Polychronicon*, Trevisa's trans., vol. ii., p. 19.

SECTION I.—PHYSIOLOGY.

PROGRESS AND PROSPECTS IN CHEMOTHERAPY.

ADDRESS BY

H. H. DALE, C.B.E., M.D., F.R.S.,

PRESIDENT OF THE SECTION.

INTRODUCTORY.

In the mind of every physiologist visiting Toronto to-day one recent advance in our science will certainly be uppermost. We rejoice with our colleagues here in a great achievement which has opened new vistas of knowledge to exploration, has brought relief to unmeasured misery, and has turned the eyes of a world, too often careless of such things, in proper gratitude and well-founded hope to this University and its Medical School. Insulin, and its still marvellous and mysterious action, have held a prominent place in the interest of many of us, myself included, during the past year or two. In one of our meetings, however, we shall have the opportunity of considering the observations and opinions of many who are now working on its properties and their significance, and among them will be some who were associated with its discovery. I have thought it appropriate, therefore, to ask your attention to-day to some recent developments in a widely different field of investigation. The subject which I have chosen presents points of general physiological and biochemical interest, apart from its immediately practical importance for the treatment of disease. It has, further, in one way, a special appropriateness to this year's meeting of the British Association. For our knowledge of an important group of diseases, caused by the parasitic trypanosomes, which have provided the experimental material for a very large proportion of chemotherapeutic investigations, we are in the largest measure indebted to the pioneer work of the distinguished President of the Association, Sir David Bruce.

I. The Theoretical Origin of Chemotherapy.

Chemotherapy may be defined as the specific treatment of infections by artificial remedies. The object of those who study it is to find new remedies which will cure or arrest diseases due to infections, not by alleviating the symptoms or invigorating the patient, but by directly and specifically suppressing the infection. Chemotherapy, in this wide sense, is not entirely of recent growth. When the natives of Peru discovered the value in fevers of the cinchona bark, which the Jesuits brought to Europe in the 17th century, they had found a specific remedy for malaria, which is still the best available. Similarly the natives of Brazil had found in ipecacuanha, which reached Europe shortly after cinchona, a remedy for amœbic dysentery better than any other which our modern systematic

and scientific efforts have produced. Modern Chemistry, indeed, has separated the alkaloids from these drugs, and has made it possible to identify among them the actively therapeutic constituents; Protozoology has revealed the nature of the infections. We know now that cinchona owes its curative action chiefly to quinine and quinidine, and that they act as specific exterminators of the malaria parasites, and not simply as remedies for fevers in general; and we know that ipecacuanha owes its action to emetine and cephæline, and that these act as exterminators of the entamœba causing tropical dysentery, and not simply as symptomatic remedies for dysenteries of any kind. But chemistry has produced no better remedy for malaria than quinine, or for amœbic dysentery than emetine; and the method by which either of these alkaloids cuts short the infection by a particular parasite, the nature of its specific action, remains a fascinating problem.

The modern development of chemotherapy, as a new department in therapeutic science, claiming the co-operation of parasitologists, microbiologists, and synthetic chemists, did not take origin, however, simply from the study of these traditional remedies. It may be regarded rather as an outcome of the study of the natural antibodies. The investigation of these natural antagonists to infection produced a new therapeutic ideal. Not only had they shown themselves to have an intensely specific affinity for the infecting organism of the toxin which caused their production; they were also perfectly harmless to the patient, behaving, in relation to his organism, as normal constituents of his body fluids and tissues. Ehrlich aptly compared them to magic bullets, constrained by a charm to fly straight to their specific objective, and to turn aside from anything else in their path.

Of the artificial remedies, on the other hand, which man had empirically discovered, even of drugs like those just mentioned as being specific for certain infections, the best that could be hoped was that they would eliminate the parasite before they poisoned the patient. And thus, when the limitations of natural immunity were becoming clearer; when it was realised that to certain forms of infection, several of which had proved to be infections by protozoa, the body was unable to produce antibodies of sufficient potency to eliminate the infection and leave the patient immune; the question arose whether, with the new and growing powers afforded by synthetic chemistry, man could not so far rival Nature's achievements as to produce, in the laboratory, substances specifically adapted to unite with and kill the protoplasm of these parasites, as the natural antibodies united with that of others, and to leave the tissues of the patient similarly unaffected. The ideal of this new and systematic Chemotherapy, as the imaginative genius of Paul Ehrlich conceived it, was to be the production by synthesis of substances with a powerful specific affinity for, and a consequent toxic action on, the protoplasm of the parasites, and none for that of the host—of substances, to use Ehrlich's own terminology, which should be maximally parasitotropic and minimally organotropic.

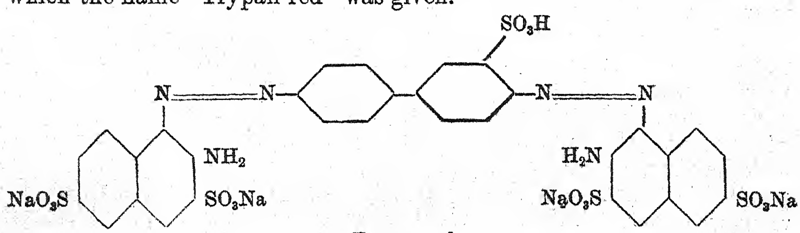
I want to invite your attention to-day to the results which, during the last twenty years, have been produced under the stimulus of this bold conception; not, indeed, to attempt a survey or summary of all that has been done, but, in the light of a few of the suggestive facts which have emerged, to consider how far this hypothesis has justified itself, and whether

it can be accepted as a safe guide to future progress, as it has undoubtedly provided the initiative and working basis for much of what has been accomplished hitherto. Before we deal with some of the actual results obtained, it may be well to consider a little more closely what Ehrlich's working hypothesis involved. The problem was to discover, by chemical synthesis, a compound which, in virtue of its chemical structure, should have a maximal affinity for the protoplasm of a microscopic parasite, such as a trypanosome, and a minimal affinity for that of the host's body cells. These affinities were pictured by Ehrlich, in the terms of his side-chain theory, as determined by certain side-chains of the complex protein molecule, or chemoreceptors, which endowed the protoplasm with specific combining properties. When it is remembered that knowledge of the chemistry of the protoplasm of a trypanosome is almost nil, and that what little we do know suggests that it is very similar to that of our own cells, it will be admitted that the enterprise was one calling for scientific courage and imagination in the highest degree. Complete failure would not have been surprising; the matter for surprise, and for admiration, is that so large a measure of practical success should, at the end of two decades, already claim record.

II. Trypanosomes and Spirochæts.

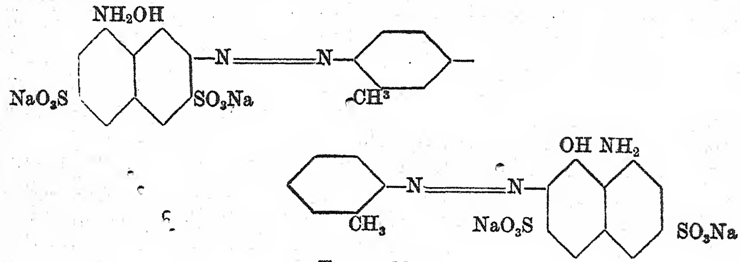
i. The Action of Dyes and Analogous Compounds.

The investigations leading, in the last few years, to a clear promise, at last, of the successful treatment of the diseases in man and animals due to infections with trypanosomes, had at least two different starting-points, the action of dyes and the action of arsenic. Ehrlich's early interest in the synthetic dyes, and his observations of the curiously selective distribution which they often exhibited among the cells and tissues of the body, naturally suggested the possibility of finding, in this group, a substance which would selectively fix itself to the parasite and poison its protoplasm, without injuring that of the host. The technique developed by Laveran and Mesnil, by which a particular strain of trypanosomes could be passed through a series of mice or rats, and produce an infection of standardised type and virulence, enabled the effect of a large selection of dyes to be investigated, with the view of finding one which would favourably influence the infection. A starting-point having been obtained, the resources of synthetic dye production were available to produce an indefinitely long series of derivatives and modifications of the active compound, each to be tested in its turn. In this way Ehrlich and Shiga arrived at a substance which gave experimental promise of curative value, a benzidine dye to which the name 'Trypan red' was given.



Trypan red

Two years later, Mesnil and Nicolle, proceeding further along the same path, described an even more favourably active blue toluidine dye, 'Trypan blue.'



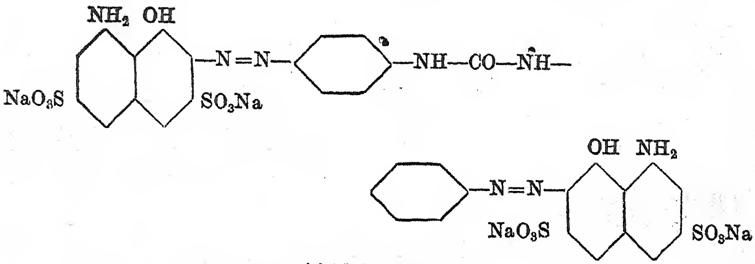
Trypan blue

This is the only one of the dyes which has hitherto had a genuine practical success in the treatment of a protozoal infection, not indeed by a trypanosome, but by an intracorpuscular parasite of the genus Piroplasma, which infects dogs and cattle. This successful application of Trypan blue to an animal disease has a special interest for us to-day, in that it resulted from the joint labours of last year's President of this Section, Professor Nuttall, with a Canadian collaborator, Dr. Hadwen.

We may turn aside at this point to enquire how far the results even of these earlier investigations corresponded with the theory which gave them their impetus. Did these dyes really act by selectively staining and killing the parasites, and leaving the host's cells untouched? The evidence was certainly not in favour of such a view. Ehrlich and Shiga themselves observed that Trypan red, even in relatively high concentrations, was practically innocuous to the trypanosomes outside the body. The trypanosomes, like other cells, were not stained by the dye until they died, and there was no clear evidence that they died sooner in the Trypan-red solution than in ordinary saline. Again, Trypan red cured an infection by the trypanosome of 'Mal de Caderas' (*T. equinum*) in the mouse, but not the same infection transferred to the guinea-pig, rat, or dog; nor did it cure an infection with the trypanosome of Nagana (*T. brucei*) in mice. Now, to explain such a difference by stating that the affinity of Trypan red for *Trypanosoma equinum* was much higher than its affinity for the tissues of the mouse, but not than its affinity for those of the rat, would be merely to restate, in terms of the theory, the observed fact that the mouse was cured while the rat was not; and the lack of direct affinity for the dye shown by trypanosomes outside the body made such an interpretation in any case unsatisfactory. One point, however, appeared very significant, and it is met repeatedly in studying the action of effectively chemotherapeutic substances, namely, that the trypanosomes treated with the dye *in vitro*, though neither obviously stained nor visibly harmed, had lost their power of infection, and died out promptly if introduced into the body of a mouse. Under such conditions only minimal traces of the dye are introduced into the animal, and we are left with a series of alternative possibilities. It is possible that sufficient dye has been taken up by the trypanosomes to kill them eventually, the period of survival *in vitro* being inadequate to display its action; or that Trypan red is converted by the

influence of the body fluids and tissues into something which is effectively lethal for the parasite; or, again, that the effect of the drug is not directly to kill the trypanosomes, but, leaving their individual vitality and motility unimpaired, so to modify them that they have lost the power of rapidly reproducing themselves and invading the fluids and tissues of the mouse's body—in other words, have lost that complex of adjustments to the various factors of the host's natural resistance which we crudely summarise as 'virulence.' Such possibilities involve either storage or modification of the dye by the host's tissues, or their essential co-operation in its curative effect.

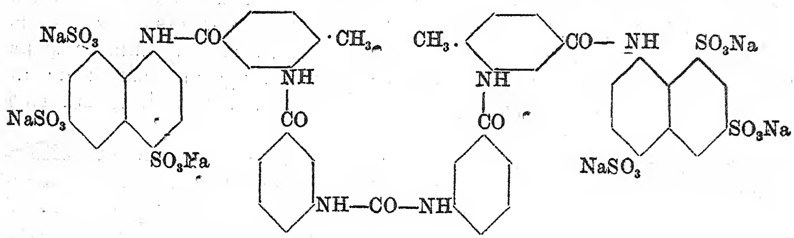
One other active dye must be mentioned as providing the link with a recent, most important advance. Mesnil and Nicolle in 1906 made some promising experiments with a dye, Afridol violet, which differed from any previously tested, in that its central nucleus was diamino-diphenyl-urea.



Afridol violet.

From this time onwards there was no further public indication of progress along these lines until 1920, when Händel and Joetten published the results obtained with a remarkable substance which, as the result of some fifteen years of continuous work by their scientific staff, had been introduced by the great dye and chemical firm of Bayer. This substance, which is not a dye, but the colourless, water-soluble salt of a complex sulphonic acid, has hitherto been known as Bayer '205,' and, for reasons which need not concern us, the firm decided not to publish its formula. To students of their patent specifications, however, it seemed pretty certain that it would prove to be one of a long series of compounds, formed of chains of amino-benzoyl radicles, united by amide linkages, with a central urea linkage, like the dye last mentioned, and terminal naphthylamine sulphonic acid groupings. A number of these substances, having no diazo-linkages, were not dyes, but there was no indication as to which constitution, out of an immense number possible, would prove to be that of the remarkable substance numbered '205.' There is a reasonable probability that its identity has now been settled by the recent work of Fourneau and his co-workers in the Pasteur Institute, who made and investigated an extensive series of compounds of this general type, and found one, which they numbered '309,' which conspicuously excelled all others, even those closely related to it, in the favourable ratio which it displayed, between a just toxic dose and that which caused a trypanosome infection in mice to disappear. As in the case of '205,' the ratio, the 'chemotherapeutic index' of Ehrlich, was found by Fourneau, in some experiments with his compounds,

to be well over 100. At least it may be said that, if M. Fourneau has not identified Bayer '205,' he has discovered another compound having very similar, and probably as valuable, properties.



Fourneau's '309' (possibly identical with 'Bayer 205').

The most remarkable property of '205' is the long persistence of its effect. A dose injected into a mouse, a rabbit, or a rat will not only free the animal, if already infected, from trypanosomes in a few days, but will also render it resistant to such infection for a period of weeks or even months. During that period its serum, or extracts from certain of its organs, exhibit a curative action if injected into another animal infected with trypanosomes.

Though there seems no reason to doubt that this substance has cured a number of cases of African sleeping-sickness in man, even some in which the disease was well advanced and in which all previously known remedies had failed, the mode of its action still presents a number of attractive obscurities. Like many other remedies which are experimentally efficient when injected into the infected animal, it has little or no obvious action when directly applied to trypanosomes *in vitro*. The paradox is, perhaps, less than usually significant in this case, since the action in the animal is delayed, a period of a few days elapsing before the trypanosomes begin to disappear from the blood. We might suppose that the action is too slow to be recognised during the period of survival of the parasites outside the body, or that it affects not the individual vitality of the trypanosomes, but their power of reproducing themselves. The latter idea is supported, as in other cases, by the fact that trypanosomes treated with the drug *in vitro*, or taken from an injected animal before the curative effect has become manifest, fail to infect another animal. It is contradicted, however, by the observation that the trypanosomes, just before the curative action begins, show not a depression, but a stimulation of reproductive activity, division forms becoming abnormally common. Is it that during or immediately after division the parasites become specially liable to the action of the drug? It may be so; but one thing seems perfectly clear, namely that the action is a very complex one, involving the co-operation, in some way, of the host. For here again it is found that the curative action, on infections by the same strain of trypanosomes, varies enormously with the species infected, a mouse being cured with ease, an ox or a horse with difficulty or not at all. A curious fact is that the rapidly progressive and fatal infections produced in mice by certain pathogenic trypanosomes are easily and certainly cured, while the apparently harmless natural infection, seen in many wild rats, by *T. lewisi* is not affected at all. Then

there are some curious records of treatment in man, in which the symptoms of sleeping-sickness have disappeared, but the trypanosomes are still found in the cerebro-spinal fluid, suggesting that, though the parasites have not been killed, they have lost their virulence and their power of invading the brain substance.

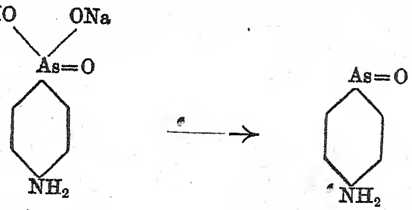
The features of the action of this remedy, however, which have most interest for the physiologist and the biochemist are those related to the long persistence of its effect. '205' has a large molecule, but it is extremely soluble in water, and diffusible through collodion membranes. How, in such circumstances, can we explain the persistence of its sterilising and prophylactic action for months after an injection? At first sight one is tempted to regard it as incredible that a substance with these properties should persist in the body for such a period, and to suggest that the action must be due to its stimulation of the body to form its own protective substances. This possibility, however, seems to be excluded by the fact that the serum of the protected animal does not lose its curative properties if heated. On the other hand, there have recently appeared, some of them only in preliminary abstract, a series of highly suggestive observations, indicating that '205' has properties of entering into a combination of some kind with the serum proteins. After standing for an hour or two in serum, '205' no longer passes into an ultra-filtrate through collodion, and if the proteins are coagulated by heat is not to be found in the filtrate. The proteins of the blood, moreover, are stated to lose many of their characteristic properties by entering into this combination, the blood losing its normal power of clotting, and the serum proteins not being precipitated by mercury salts or tannin.

It would be both useless and presumptuous for a mere onlooker to speculate in detail on the significance, for the curative action of '205,' of properties which are only now beginning to be investigated. One conclusion, however, I think we are entitled to draw. It is sufficiently evident that here is no question of a substance curing simply on account of its affinity for parasites and lack of affinity for the host's tissues. What direct action on the parasite '205' itself may possess has still to be demonstrated; we may feel reasonably certain, on the other hand, that its affinities for the constituents of the host's blood and tissues play an important part in its remarkable and peculiar curative properties.

ii. Derivatives of Arsenic.

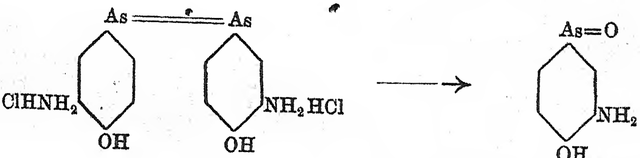
In the case of the other series of investigations which I mentioned, that dealing with the organic derivatives of arsenic, we find again many difficulties, in the way of the simple theory, of a cure due to distribution by chemical affinities. None of the compounds of this series, which have reached practical trial and success in the treatment of spirochætal or trypanosomal infections, atoxyl, salvarsan, or tryparsamide, has a directly lethal action on the parasites in dilutions at all comparable to those which can be safely and effectively produced in the body of the host. The paradox of this direct inertness of atoxyl, the starting-point of the series, seemed to be explained when Ehrlich showed that its reduction to the corresponding arsenoxide produced a substance with an intense

directly lethal action on trypanosomes. Similarly the partial oxidation of salvarsan, to the corresponding arsenoxide, produced a substance having



'Atoxyl' Arsenoxide from 'Atoxyl'

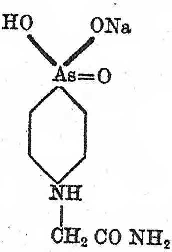
the intensely lethal action on spirochæts or trypanosomes *in vitro*, which salvarsan itself conspicuously and paradoxically lacked. In these cases, we may make the supposition, which Voegtlin and his co-workers, especially, have recently supported by detailed evidence, that the reduction or



'Salvarsan' Arsenoxide from 'Salvarsan'

oxidation effected by contact with the tissues is the essential preliminary to the curative action; a supposition which, it will be noted, again introduces the host as an essential participant in the cure. The fact, that the administration of these relatively inactive predecessors is therapeutically more effective than the injection of the directly active oxides derived from them, would then be explained on the assumption that the slow liberation of these latter in the body, at a rate which never produces a high concentration, provides the optimum condition for their persistent action on the parasites, without danger to the host. This slow and persistent liberation of the directly active substance would be favoured by the physical properties of salvarsan, which at the reaction of the body is practically insoluble, and must be rapidly deposited after injection.

In their recent work on the action of Tryparsamide, the compound,



Tryparsamide

prepared by Jacobs and Heidelberger at the Rockefeller Institute, which has shared with Bayer '205' the credit of making the eventual conquest

of African sleeping-sickness a hopeful possibility, Brown and Pearce find it necessary to introduce yet other considerations to explain its effects. Tested by Ehrlich's therapeutic index—the ratio between the lowest curative and the highest non-toxic dose—it gives a relatively unfavourable figure. Brown and Pearce practically abandon the attempt to account for its action on the supposition that it directly kills the parasites, and attribute its value largely to its power of penetrating easily into the tissues and reinforcing there the processes of natural resistance.

iii. Action of Bismuth.

Another conception of the mode of action of these arsenical remedies, also involving a direct participation in the host's tissues, was put forward by Levaditi. He found that from atoxyl a directly parasiticidal preparation could be obtained, by incubating it with an emulsion of fresh liver substance. As the first step, therefore, in the curative action of atoxyl, he postulated a combination of its reduction product with some constituent of the liver or other tissue, giving rise to the essential curative complex, which he named 'trypanotoxyl.' Levaditi's observations were explained by Ehrlich and Roehl as due simply to the reducing action of the liver substance on atoxyl; but it would be difficult to apply this explanation to the quite recently published observations by Levaditi and his colleagues, on the mode of action of bismuth in curing spirochætal infections. A sodium potassium bismuthyl tartrate—a bismuth analogue of tartar emetic—had been found to have valuable curative properties in syphilis and other spirochætal infections. Later, various other bismuth salts, bismuth suboxide, and even finely divided metallic bismuth, were found to produce similar effects. According to Levaditi and Nicolau, these preparations have, by themelves, a relatively weak action, or none at all, on the spirochæts outside the body. If they are mixed, however, with a cell-free extract of liver, which is itself harmless to spirochæts, the mixture, after incubation, acquires a potent spirochæticidal action. The possibility of a mere reducing action of the liver extract seems here to be excluded, since bismuthous oxide, or metallic bismuth itself, yields a spirochæticidal mixture, containing Levaditi's hypothetical 'bismoxyl,' when incubated with the liver extract. If these observations are confirmed, there will be a strong indication that some cell-constituent enters into the composition of, or is essential to the formation of, the directly active substance from any of the derivatives of arsenic, antimony, or bismuth, as a preliminary to its action on an infection due to a trypanosome or a spirochæt. Again we have evidence of an organotropic property of the remedy, as an essential condition of its activity.

iv. Resistant Strains of Trypanosomes.

In the phenomena of the acquisition of resistance, by a strain of infecting trypanosomes to a particular curative drug, discovered and largely worked out in Ehrlich's laboratory, we meet again with facts which can only with the greatest difficulty be reconciled with the assumption that the drug directly attacks the parasites. It was found, for example, that if a mouse infected with trypanosomes received an incompletely effective series of doses of atoxyl, the trypanosomes appearing in the blood at each relapse were more and more resistant to the drug, until they could not

be caused to disappear by any dose of atoxyl which the mouse would tolerate. The strain, having once acquired this resistance, would retain it, on passage through an indefinitely long series of mice, without further treatment. Mesnil and Brimont, however, made the remarkable observation that, if the strain of trypanosomes was transferred to a rat, it immediately became in that animal susceptible again to treatment with atoxyl, remained so as long as it was kept in rats, to reacquire its old resistance to atoxyl as soon as it was re-transferred to mice. Such a fact seems to be not at all explicable on the theory that the directly active agent, to which the trypanosome becomes resistant, is a mere reduction product of atoxyl; it is much more easily reconciled with a mechanism such as that described by Levaditi, in which a constituent of the host's tissues enters into the formation of the trypanocidal substance. We can imagine the trypanosome becoming immune to Levaditi's mouse-trypanotoxyl, and remaining susceptible to the corresponding rat-product.

The whole question of this acquired resistance of the parasites to the action of curative drugs bristles with points of difficulty and interest. Ehrlich attributed the sensitiveness of the parasite, for a particular curative agent, to the possession by its protoplasmic molecule of a special form of side chain, or 'chemoreceptor,' which determined its affinity for that agent. When the trypanosome became resistant, it was simple to suppose that it did so by losing the appropriate chemoreceptors; an atoxyl-resistant trypanosome, for example, had lost its atoxyl receptors. Apart from the objections already mentioned, this conception met a new difficulty, when in Ehrlich's laboratory it was found that the resistance was by no means as rigidly specific, as it had first appeared to be. Not only imperfect treatment with atoxyl, but treatment with a particular group of dyes, having no kind of chemical relation to it, was found to produce a race of trypanosomes resistant to atoxyl and to other arsenical derivatives. To suggest that the chemoreceptors for arsenic and for these dyes are identical is merely to restate the fact of this reciprocal action in terms having no definite meaning. Obviously no more precise conception as to its significance can be formed until we know something more of the conditions on which resistance and susceptibility depend. A recent suggestion by Voegtlin has interest in making, at least, an attempt at interpretation in more definite biochemical terms. Voegtlin and his co-workers point out that arsenious oxide and its derivatives readily combine with substances containing a sulphydrile grouping, and find that the toxic action of the organic arsenoxides, on trypanosome and mammal alike, is depressed by the simultaneous injection of excess of various sulphydrile compounds.

$$\mathrm{R{\cdot}As{=}O} + \frac{\mathrm{HS{\cdot}R}}{\mathrm{HS{\cdot}R}} = \mathrm{R{\cdot}As}\begin{cases}\mathrm{S{\cdot}R}\\ \mathrm{S{\cdot}R}\end{cases} + \mathrm{H_2O}.$$

III. Suggested Reaction of an Arsenoxide with a Sulphydrile Compound.

The work of Hopkins, showing the importance of one such sulphydrile compound, reduced glutathione, in the hydrolytic oxidation-reduction processes of the cell, suggests to Voegtlin that a combination with such groups, and consequent suppression of this vital function, may explain

the toxic and curative actions of the arsenical derivatives, and that a formation by the trypanosome of the sulphydrile compound, in excess of its vital need, may be the basis of acquired resistance. If certain dyes similarly affect this cellular oxidation system, the production under their influence of strains of trypanosomes resistant to arsenic would also be explained. So stated the suggestion leaves many aspects of the problem still unconsidered; but it may at least be allowed the merit of an attempt to interpret the action of these drugs in terms of known biochemical facts.

IV. Emetine and Dysentery.

To turn to another example of a chemotherapeutic problem, I may mention briefly some results obtained, some years ago, by Mr. Clifford Dobell and myself, in an attempt to explore the curative action of emetine and the other alkaloids of ipecacuanha in amœbic dysentery, with a view to finding a more effective treatment. At the time when we took up the problem it seemed simple. Rogers had recorded that the amœbæ obtained from a case of amœbic dysentery, and treated *in vitro* with emetine, were rapidly killed by the alkaloid in dilutions as high as one part in 100,000. This seemed to explain the action of emetine as a simple and direct one on the parasites, and to provide a rapid method for testing a series of compounds for their therapeutic possibilities. We failed, however, as other observers before and since have done, to confirm the observation; on the contrary, we found that the dysenteric amœbæ, obtained from cats secondarily infected, or, in a control observation, directly from man, were surprisingly insusceptible to the action of emetine, living for hours in concentrations much greater than the highest which they would tolerate of other alkaloids, which had no curative action in dysentery. One of the other natural alkaloids of ipecacuanha, methyl-psychotrine, and certain artificial derivatives of emetine, were much more effective in killing the amœbæ in the test tube, and at the same time were practically devoid of the characteristic toxicity of emetine and cephæline for mammals and for man. Here, on the classical assumption of chemotherapy, should have been ideal remedies for amœbic infection—substances much more parasitotropic and much less organotropic than those already known to be effective. Yet each of them in turn, when administered to patients suffering from amœbic dysentery, in doses much larger than those in which emetine could be tolerated, produced no effect whatever on the dysentery, which promptly cleared up when emetine was subsequently given. Among the members of this group of alkaloids which were tried, the curative effect seemed to be proportional rather to their toxic and nauseating action on the patient, than to their lethal action on the isolated amœbæ. Yet emetine and cephæline are not mere symptomatic remedies; they definitely stop the progress of infection by the amœbæ, and, properly administered, eliminate them altogether from the body.

Yet another puzzling observation, made by Dobell and myself, was that an amœbic infection which readily yielded to treatment with emetine in man, was entirely uninfluenced by emetine when transferred to the cat. In no way is it possible to account for these facts without admitting a co-operation of the patient's tissues in the curative action; nor, with that admission, can we do more than consider possibilities. We only know that

the truly parasitic *Entamœba histolytica,* which cannot live without invading the tissues, can be checked in this invasion and eliminated from the body by administering emetine, while other Entamœbæ, which live on fæcal debris, remain unharmed. Whether the tissues are so altered that the amœbæ cannot invade them, or the amœbæ, without being directly killed, are so weakened in virulence that they cannot invade the tissue and obtain their food, but succumb in face of the normal resisting powers of the host, are possibilities on which we can only speculate, and no method of bringing them to the test of experiment has yet been found.

The work of Morgenroth and his co-workers, extending now over more than a decade, has again led them to emphasise, in connexion with the curative action of substances which they have examined, a fixation to the cells and tissues of the host, a definitely organotropic property, as an important factor in the effect. Two examples may be mentioned.

V. Quinine and Malaria.

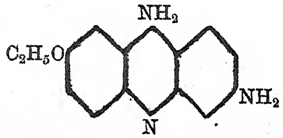
One of the earliest of chemotherapeutic discoveries, that of the cure of malaria by quinine, had never been satisfactorily explained. There was no evidence establishing even a probability that quinine, in such concentrations as can be tolerated in the blood of the living subject, would directly kill the malarial plasmodia, especially if these were partly screened from its action by their position in the interior of the red corpuscles. Morgenroth, from the results of his determinations by biological methods of the distribution of quinine in blood, is led to the conception of quinine as acting on malaria, in virtue of its fixation by the red corpuscles, either killing the trophozoites in their interior, or blocking the entry into them of the merozoites of the asexual cycle. On this latter supposition, it will be seen that quinine would act, not by killing the malarial parasites, but by rendering the blood unfitted for their multiplication. They are supposed to fall a prey to the natural defensive substances in the plasma, because a film of quinine denies them access to the red corpuscles, in the interior of which they could continue their development in safety. There are discrepancies between Morgenroth's determinations of the distribution of quinine in favour of the red corpuscles, and those obtained by direct chemical means, which would still need to be reconciled, before either theory of the curative process in malaria could be fully accepted. Meanwhile, these suggestions are of interest, as another example of the need found, more and more, by workers in this field, to regard an organotropic property of a drug, not as detrimental to its curative action, but as an essential factor in the chemotherapeutic process.

VI. Remedies for Bacterial Infections.

This same property, of fixing themselves to the red blood corpuscles or to the connective tissue, has been observed by Morgenroth and his co-workers with the higher homologues of quinine, ethylhydrocupreine ('optochin'), and octylhydrocupreine ('vuzin'), and with the dyes of the acridine series, with which they have obtained promising results in the treatment of bacterial infections. In the treatment of pneumococcus infections by optochin several factors, other than those of immediately

lethal action of the alkaloid on the pneumococci, appear to be concerned. Evidence was obtained by Moore, for example, which suggested that the defensive reaction of the host was an essential factor in the cure, optochin, in doses inadequate to kill the pneumococci, rendering them liable to the action of specific antibodies; and some experiments of Felton and Dougherty suggest that an excessive dose of an alkaloid of this class, by suppressing the natural defensive reaction, may even allow the fatal spread of an infection which a lower dose would cure. Morgenroth, on the other hand, emphasises the part played by the organotropic properties of optochin and vuzin, in enabling the red corpuscles to act as carriers of the drug to the point of action, and the connective tissues to form local depots of it.

An acridine dye, named Trypaflavin, was under study in Ehrlich's laboratory in 1914 as a trypanocidal remedy, and was found during the war, by Browning and his co-workers, to have valuable properties as an antiseptic for infected wounds and mucous membranes, for which, under the name 'Acriflavine,' it is still used. Since the war, other dyes of this series have been investigated by Morgenroth and his school, and one of them, called 'Rivanol,' is stated to be particularly effective as a tissue antiseptic, especially in conditions of spreading infection due to streptococci.



'Rivanol' (2-ethoxy 6, 9 diamino acridine).

In the case of 'Rivanol' also, evidence has been brought forward that it is fixed by the red corpuscles and the subcutaneous tissues, protected thereby from excretion, or held at the point where its curative action is required. From these body cells it is suggested that the dye is gradually given up to the cocci, on which its action is exerted, by a process called 'transgression' by Morgenroth. This is a process by which a substance is passed from one medium to another, when both have strong affinities for it, through a layer of an intervening medium for which it has no affinity, and in which it may be almost insoluble. In this process of depot formation, and gradual liberation of the active substance, we are concerned with a phenomenon which certainly has a widespread importance for chemotherapeutic action. We have earlier seen evidence of such fixation and gradual release in the cases of Bayer '205' and Salvarsan.

Another suggestive feature of the action of 'Rivanol' on streptococcal infections, is that such organisms as escape the immediately lethal effect of the dye appear to have lost their hæmolytic properties, and to have been modified into a relatively avirulant strain.

VII. Conclusion.

We have considered but a few examples of the directions in which chemotherapeutic investigation has proved practically fruitful, including some in which it shows, at the moment, the most hopeful signs of progress. If one considers any one group of investigations by itself, one may easily feel, at the same time, elated by the practical success obtained, in the cure of some infection which, but a few years ago, seemed beyond the reach of treatment, and depressed by the disharmony between the results of experiment and the theoretical conceptions, hitherto available, of the nature of the chemotherapeutic process. Some of the most notable practical triumphs in this field have resulted, not from experimental investigations based on theory, but from an almost empirical trial, on human patients suffering from one type of infection, of a remedy which had experimentally shown promising results in infections of a different, and sometimes of a widely different, type. The partial success of tartar emetic in trypanosome infections might have justified a hope that it would have some effect in kala-azar, but hardly a prediction of its really remarkable efficacy in that previously intractable form of infection. Still less would it have justified expectation of the brillant success of this same drug in infections by the Schistosoma or Bilharzia-worm, which but recently seemed almost beyond the hope of any kind of treatment. With such instances in mind, one might, but a year or two ago, have been tempted to suggest that the attempts at theoretical investigation, of the intimate mechanism of the chemotherapeutic process, had contributed little to the practical achievements, and that a reasonably intelligent empiricism was still the safest guide. I do not think that the suggestion would even then have been defensible, and it would assuredly have been stultified by the results of the past few years. Patient, systematic exploration, by routes of which the initial sections were already mapped in the early days of chemotherapy, has in these recent years again led to results of major importance, both for practical therapeutics and for the theoretical basis of future advance. That the original theoretical framework begins to show itself inadequate for the expanding fabric is good reason for its reconstruction; but we may well beware of hasty and whoesale rejection, remembering that it served the early builders well. I think that it is especially encouraging to note that, though, in the action of almost every remedy which has proved its value in the specific cure of infection, there are features which cannot be interpreted by a strict application of Ehrlich's distribution hypothesis, the discrepancies begin to show a new congruity among themselves. Repeatedly we find phenomena which point to the need of modifying the theoretical structure in the same direction. The conception of a remedy not killing the parasites immediately, but modifying their virulence, or lowering their resistance to the body's natural defences; of a remedy not acting as such, but in virtue of the formation from it in the body of some directly toxic product, either by a modification of its structure or by its union with some tissue constituent; of an affinity of the remedy for certain cells of the host's body, leading to the formation of a depot from which, in long persistent, never dangerous concentration, the curative substance is slowly released; all these conceptions present themselves, again and again, as necessary for our

present rationalisation of the effects observed. It can hardly be doubted that they will potently influence the methods by which, in the immediate future, new and still better specific remedies are sought. But though our practical aim, in relation to the affinities of a remedy for the parasite and for the host's tissues, may be radically changed, the meaning of these specific affinities, so delicately adjusted to a precise molecular pattern, remains dark. Ehrlich's chemoreceptors may no longer satisfy us, but we have nothing equally definite to replace them. I have endeavoured to indicate what seem to me hopeful signs of new contacts between biochemistry and chemotherapy. There is promise, in another direction, that at least some aspects of the problem of immune specificity are being brought within the scope of strictly chemical investigation, as in the recent work of Avery and Heidelberger, on the constituent of a pneumococcus which combines with the specific precipitin. As in Ehrlich's pioneer work in chemotherapy, it can hardly be doubted that an increased understanding of the meaning of immune specificity, which but a short while ago might have seemed hopelessly beyond the range of attack by chemical weapons, will still influence ideas, and help to shape the course of further investigations, on the chemotherapeutic process. As the biological complexity of the problem is realised, it becomes increasingly a matter for wonder and admiration that so much of practical value has already been achieved —the treatment of the spirochætal infections, syphilis, yaws and relapsing fever, revolutionised; Leishmania infections, kala-azar and Baghdad boil, and Bilharzia infections, which crippled the health of whole populations in countries such as Egypt, now made definitely curable; trypanosome infections, such as the deadly African sleeping-sickness, after years of alternating promise and disappointment, brought now at last within the range of effective treatment. And if such results have already been attained, in a period during which practice has often and inevitably outrun theory, we may well be hopeful for a future, in which fuller understanding should make for more orderly progress.

SECTION J.—PSYCHOLOGY.

PURPOSIVE STRIVING AS A FUNDAMENTAL CATEGORY OF PSYCHOLOGY.

ADDRESS BY

PROFESSOR WILLIAM McDOUGALL, F.R.S.,

PRESIDENT OF THE SECTION.

We who are workers in the various fields of Psychology are happy in the knowledge that our science is rapidly developing, extending its influence into every sphere of human activity. The institution and the success of this section of the British Association are good evidence that our colleagues in the other branches of natural science have recognised the claim of Psychology to take its place among those other branches. And, though in Great Britain there are still all too few Chairs of Psychology, in Canada and America the Universities and Colleges are now providing abundant opportunities for teachers, students, and research workers, opportunities that are being eagerly and fully used.

Yet, in spite of this happy state of affairs, there is manifested among us psychologists a certain uneasiness as to the status of our science, an anxiety lest the psychologist be regarded as not quite really and truly a man of science. This anxiety is, I think, exerting an unfortunate influence on the development of our science, an influence which shows itself in two principal directions.

On the one hand is a group of psychologists, who, actuated by the desire to mark off an exclusive field of study as their province, define psychology as the science of consciousness and would confine themselves to the analytic description of conscious states as complex conjunctions of elements or units of some kind. On the other hand are those who, feeling that such analytic description, whether it resolves consciousness into a complex of sensations or atoms of consciousness, or into larger more complex units (the so-called configurations or *Gestalten*), brings but little light on human nature and conduct, and can hardly claim to be in itself a science, are driven to the opposite extreme; they ignore this realm of facts, alleged to be the peculiar and distinctive field of psychology, and they would bring to the study of man only those methods of observation, description, and explanation which are used in the physical sciences. These two tendencies, which, when they are carried to extremes, result respectively in what is unfortunately called 'structural psychology' and in 'behaviorism,' although so different in their outcome, are but two expressions of one desire, the desire to make psychology conform to some preconceived notion of what a science is or should be. The 'structuralist'

aims at marking out a peculiar and exclusive field of objects of study. The 'behaviorist' slavishly accepts the physical sciences as his model, and seeks safety from the charge of being unscientific by confining himself to the use of the methods of observation, description, and explanation current in those sciences.

Although a very considerable number of psychologists are following these two widely divergent lines (especially, perhaps, in America), I may, I think, take it for granted that to the majority of us neither line is satisfactory. We feel that both are the expression of a lack of courage; of an undue timidity. In face of the imposing edifice of the physical sciences, the one party shrinks back and seeks to define a little field of knowledge altogether peculiar to itself, within which the psychologist can disport himself at his own sweet will without fear of collision or conflict with the other sciences; the other party seeks safety by taking cover in the bosom of the herd, carefully avoiding all speech or action that might, by marking him as a distinctive variety of the species scientist, bring upon him the suspicious glances of other members of the herd.

There is yet a third large group of psychologists who, moved by the same desire as these others, yet seeing that neither group achieves, nor can hope to achieve, a satisfactory science of human nature and conduct, seek to escape from the limitations of both groups by combining the procedures and the conclusions of both. These adopt the analytic description of consciousness (whether of the 'sensationists' or the 'configurationists') and they accept the mechanistic explanation of conduct of the 'behaviorists'; and they seek (by the aid of the principle of psycho-physical parallelism or of epiphenomenalism) to put the two together in parallel columns, to form what can only be called a lame apology for a science.

The very fact that this undue timidity has produced these two widely divergent and aberrant (not to say abortive) types of psychology is its sufficient condemnation. We should take warning from it; we should be led by it to see that a policy of courage is also the policy of safety. I urge that we psychologists are now numerous enough and strong enough to stand together, to form our own herd, a herd in which our more timid members may find the shelter which they crave. In other words, I urge that the time has come when the students of human nature should boldly claim autonomy, or, at any rate, dominion-status, for their science; they should invoke and boldly apply the principle of self-determination.

I urge that this policy of safety through boldness is justified and demanded at the present time by considerations of three kinds, in addition to the fact of the unsatisfactory results of the policy of timidity which I have already indicated.

First, psychology has now at its command an immense mass of data, facts of introspective observation and facts of behaviour, demanding to be synthesised in our science, not merely to be placed side by side in parallel columns.

Secondly, psychology has found many important fields of application, in education, in medicine, in industry, in the social sciences; and all these require a psychology, a science of human nature, very different from the mere description of consciousness and from the mechanistic explanation of behaviour, and different also from the parallel-column psychology.

Thirdly, the policy of boldness is abundantly justified by the present state of the other natural sciences.

I propose to dwell briefly upon each of the three classes of consideration in turn. And in relation to each I desire to urge that the most fundamental need of psychology, the first demand to be met by the policy of boldness, is the adoption without reserve of the conception of purposive striving as valid, useful, nay, indispensable, and therefore true.

The life of man from birth to death is one long series of purposive strivings. Sometimes, as when he plans his career and sets out to build up a home and a family, his goal is remote and somewhat vague, defined in his mind in general terms only ; sometimes it is precisely and exactly defined, as when he goes to eat his favourite dinner at his favourite table in his club ; sometimes it is near and yet but vaguely defined, as when, with open mouth and feeble movements of head and trunk, he seeks the nipple of his mother's breast ; or when, during an absorbing after-dinner conversation, he reaches out to put a piece of candy in his mouth. There is a vast range of differences in respect of the nearness or remoteness of the goal ; and in respect also of the clearness, fullness, and adequacy with which he thinks of his goal. And there is also a wide range of differences between his successive strivings in a third respect, namely, in respect of the urgency, the intensity, the concentration and output of energy manifested in his striving at any movement. Yet, in spite of these wide differences, the striving is always one aspect of his waking life. And even in his dreams, as we now realise, thanks to Professor Freud, the striving goes on, bringing what strange and partial satisfactions it may to the buried, thwarted and denied tendencies of his nature. From top to bottom of this scale of strivings we have to do with the same fundamental phenomenon. In the instances near the top, the more developed modes of mental life, involving the solving of a defined problem, the thinking out of a plan, we all recognise the purposive nature of the striving. The goal, as envisaged, governs the movements of both mind and body.

In instances at the lower end of the scale, introspection, or rather retrospection, inevitably fails to seize and report the thinking of the goal as distinct from the perceiving of the situation of the moment. Yet the continuity of the series justifies us in regarding its lower members as fundamentally of the same nature as its upper members, and in applying the term 'purposive' to them all alike.

Even in laboratory experiment, where the conditions are commonly so set as to reduce the striving factor to a dead level of uniformity and monotony, it refuses to be ignored for ever ; and so, after a generation of experimentation that ignored it, it is rediscovered and reinstalled in its place of fundamental importance, disguised under some such terminology as 'determining tendency,' or 'motor set,' or 'conditioned reflex,' or 'prepotent reflex,' or what not.

Under all three of the types of psychology we have noticed, this most vital, essential, distinctive aspect of human life escapes the psychologist. For it cannot be described as either a sensation or a configuration (*Gestalt*). And it is not to be discerned by an inspection of the detailed movements of the limbs or of other bodily organs, no matter how exact.

Nor can it be restored or recovered in the psychology of parallel columns. It can be discerned in others only by sympathetic observation and inter-

pretation of the course of their lives. If, under the influence of any metaphysical dogma or any supposed rule of method, you overlook it from the start, you cannot introduce it into your otherwise completed picture of human nature, as an element to be added to and put alongside others already described.

It is too all-pervasive for such treatment. As well might the landscape artist, after painting a picture without atmosphere, attempt to add it by drawing a smear of paint across the whole. This is the difficulty found by students who have been brought up on the parallel-column psychology, as I know from instances of such students who have found difficulty with my frankly purposive 'Outline of Psychology'; nor are such students helped to a truer view of human nature by those books on psychology which, after describing man after one or other of the three fashions we have noted, throw in perfunctorily as an afterthought a chapter on 'The Will.' If striving has been ignored throughout the composition, 'The Will' cannot be added to the picture as a finishing touch. Having learnt to look upon man as a bundle of mechanical reflexes, a superior penny-in-the-slot machine, whose workings are mysteriously accompanied by various 'elements of consciousness,' they can find no place in their completed picture for yet another element called 'a purpose'; it refuses to fit in among the other blocks; there is no room for it, and, as they think, no need for it; and it seems to them quite an ambiguous, not to say shady and suspicious, character; at best it appears to them as a disturbing intruder.

But let the budding psychologist ponder some phase of human life that is dominated by some strong but thwarted desire. Let him consider the strange yet familiar case of Romeo seeking the Juliet who is forbidden to him. How this desire to see, to hear, to touch the loved one dominates his life, waking and sleeping! How it fevers his blood; wears him to a shadow; keeps him running to and fro, scheming, trying, hoping, desponding, exulting, despairing, and always desiring! The desire governs all his thinking and acting; the most rooted habits and mental associations are as nothing in the course of this torrent of purposive activity, all directed to Nature's most imperative goal.

Can we accept any account, any description or explanation of human life, which leaves out of the picture this all-important aspect that we call impulse, desire, striving towards a goal?

When we turn to the fields of applied psychology, the same truth stares us in the face. In every field we find that the most urgent practical problems are concerned with the striving aspect of human nature. The most fundamental task of the educator is to awaken an interest in and a desire for knowledge and self-development. The psychiatrist must study and redirect if possible the conflicting desires of his patient, his subconscious as well as his conscious motives and impulses.

The personnel manager is chiefly concerned with incentives, rewards, jealousies, rivalries, discontents, loyalties, ambitions, and aspirations. The lawyer, the judge, and the jurymen are primarily concerned to determine motives, intentions, and responsibility. The politician, the economist, and the moralist are, or should be, primarily concerned with relative values and the means to make real or actual the highest values of mankind, by harmonising and co-ordinating the conflicting motives of our social life.

In all these cases a psychology that ignores the all pervading purposiveness of human life is of no use; for, if it is consistent, important words that are essential to the intelligent discussion of human affairs (such words as motive, intention, desire, will, responsibility, aspiration, ideal, striving, effort, interest) are of no meaning for it; or, if they are used, are used with a meaning so thin and so different from that of ordinary discourse, that profitable converse with the practical man is impossible.

I leave that large topic with these few words and pass to my third consideration in support of the policy of boldness. Thirty to forty years ago, when I began to study science, considerable moral courage would have been required to insist upon the purposive nature of man. For at that time the great wave of scientific materialism was still but little past its climax. It was the day of Spencer and Huxley, of Clifford and Tyndal, of Lange and Weismann, of Verworn and Bain. The world and all the living things in it were presented to us with so much prestige and confidence, as one vast system of mechanistic determination, that one seemed to be placed before two acutely opposed alternatives: on the one hand, science and universal mechanism; on the other hand, humanism, religion, mysticism and superstition.

But to-day how different is the situation! Even at the date I speak of, a few great physicists warned us against regarding the principles of physical science as adequate to the interpretation of human life. And to-day those few voices have swelled to a chorus which even the deafest biologist can hardly ignore. Einstein and Eddington and Soddy and a score of others repeat the warnings of Maxwell and Kelvin and Poynting and Rayleigh. And the physical universe of eternal hard atoms and universal elastic ether, the realm of pure mechanics, has become a welter of entities and activities which change and develop and disappear like the figures of the kaleidoscope. The psychologist who would believe in the efficiency of human effort no longer needs to fling himself in vain against the problem—How can Mind deflect an atom from its predetermined course? For the atoms are gone; matter has resolved itself into energy; and what energy is no man can tell, beyond saying—It is the possibility of change, of further evolution.

In physiology the mechanistic confidence of the nineteenth century is fading away, as the complexity of the living organism is more fully realised, as its powers of compensation, self-regulation, reproduction and repair are more fully explored.

In general biology the mechanistic Neo-Darwinism is bankrupt before the problems of evolution, the origin of variations and mutations, the differentiation and specialisation of instincts, the increasing rôle of intelligent adaptation, the predominance of mind in the later stages of the evolutionary process, the indications of purposive striving at even the lowest levels, the combination of marvellous persistency of type with indefinite plasticity which pervades the realm of life and which finds its only analogue in the steadfast purposive adaptive striving of a resolute personality.

All these considerations, I say, should encourage us to claim autonomy for psychology, the right to choose, shape, and refine its own fundamental conceptions. We should now easily find the courage to be anthropomorphic in describing man. Instead of accepting the abstract conceptions of physical science and attempting to build up from them a plausible

mechanical dummy which shall stand for man in our science, let us frankly acknowledge that man is that thing in all the world with which we have the most intimate acquaintance. Let us begin by accepting him for what he seems to be, a thinking being that strives to attain the goals he desires, to realise his ideals, sometimes succeeding, often failing, but always striving so long as he lives. Let us try to understand the history of these tendencies to strive, as they are revealed in the individual and the species; to understand more nearly our knowing, our imagining, our recollecting, our judging and reasoning, as they serve us in our strivings for the attainment of our goals.

As we progress with this task, let us cautiously extend the same principles of explanation to the animals of successively lower levels. And, when in this way we shall have gained some understanding of the life of the animalcule, we shall, perhaps, be able to begin to understand the physiology of the complex organism in its broader aspects. Instead of trying to illuminate human society by likening it to an animal mechanism, as was the fashion of the nineteenth century, we may find that we can profitably invert the process, that we can illuminate the complex organism by likening it to a well-organised harmonious human society, a society which can adjust itself to a thousand disturbances and can recover itself from grave disorders, just because and in so far as each member, endowed with limited powers of adaptation, steadfastly strives always to achieve the goal prescribed by his own nature and by his active relations with all his fellow-citizens.

But here we shall be met again by the cry of the timid psychologist. 'You are not scientific,' he will say, 'for you are disregarding the fundamental postulate of all science, namely, that all events are strictly determined, that mechanistic causation rules universally.' To this we can only reply by exhorting him once more to have courage, assuring him that 'Not all propositions made by all philosophers are true, neither does a proposition become true through being frequently repeated.'

Let us be content to postpone metaphysics and to start out from two indisputable empirical facts: first, the fact that sometimes men create new things, such as great works of art and literature and new scientific formulæ. Secondly, the fact that, when the normal man simply and strongly desires a certain end and perceives certain bodily movements to be means to that end, those movements follow upon that desire and that perception. Here are well-established empirical generalisations from which we may confidently start out, refusing to be held up by questions at present insoluble, such as—How can consciousness deflect the path of a single molecule in my brain? Answers to such questions are quite unnecessary as foundations for purposive psychology. It is in the highest degree probable that, as Science progresses, it will become clear that such insoluble questions have been wrongly stated and should never have been asked.

Let us not deny ourselves the right to build up a psychology that may be of use and value to our fellow-workers in the social sciences, because we cannot at present answer the most difficult of all questions. The physicist is equally non-plussed if you ask him comparable questions, such as—How does one molecule attract or repel another? What is the nature of chemical affinity? What is electricity? But he does not

suspend his researches because his fundamental conceptions and assumptions are disputable and disputed; nor does he turn to some other branch of science in order to borrow from it others that have more prestige. Let us follow his example.

Let us gather our facts of human nature by objective and by introspective observation. Let us make our empirical generalisations and correlations of these facts, building up our own science in our own way. Let us boldly affirm that, just as the physical sciences do not proceed deductively from any system of exact abstract propositions, so also psychology, the most concrete of the sciences, is not required by any higher authority to accept or formulate any abstract propositions as an unchanging deductive basis.

It may be that eventually men of science will agree that there are in the universe two ultimately different kinds of process, the mechanistic and the purposive, the strictly determined and the creative, the physical and the mental. Or it may be that, eventually, one of these may be shown to be merely an appearance of the other, an appearance due to the present limitations and imperfections of our understanding. At present we cannot decide this issue.

But, if I attempt to guess at the future development of Science, I incline to follow the lead of the most powerful intellects of all ages, and to predict that, if such resolution of the two types of process into one shall ever be achieved, the purposive type that we regard as the expression of Mind will be found to be more real than the other.

SECTION K.—BOTANY.

PHYSIOLOGICAL ASPECTS OF PARASITISM.

ADDRESS BY
PROFESSOR V. H. BLACKMAN, Sc.D., F.R.S.,
PRESIDENT OF THE SECTION.

The President of the Association will have expressed the satisfaction which all the Sections feel in meeting for the fourth time in the history of the Association in the great Dominion of Canada. To Section K the almost overwhelming size of the country and the great diversity of vegetation, both natural and artificial, must have an especial appeal.

Last year the President of Section K had to deplore the loss of three prominent botanists. I am less unfortunate in that our loss this year is far lighter. We have, however, to regret the death of Thomas Frederick Cheeseman, a distinguished worker in systematic botany who devoted himself to the study of the flora of New Zealand.

In deciding on the subject of a Presidential Address, the vastness of Canada's agricultural and sylvicultural interests can hardly be overlooked, even in a section the interests of whose members are in the main those of pure botany. It appeared to me appropriate that if possible some aspect of pure botany should be chosen which would have at least implications in applied botany. The subject of disease is, of course, one of great moment wherever plants are massed together in artificial cultivation. Some aspect, therefore, of plant pathology seemed a fit subject for an address on such an occasion, since in it we have a branch of botany securely based on scientific interest and firmly buttressed by economic importance. Some consideration of disease in plants seemed peculiarly apposite also when it is recalled that at the last meeting of the British Association at Toronto, in 1897, the President of this Section was Professor Marshall Ward, the first English plant pathologist of the modern school. The value of his contributions to our knowledge of disease in plants is recognised by all; that he should have been cut off in his prime, British botanists will long deplore.

It is significant of the growth of botany in all its branches that Marshall Ward set himself as his presidential task a wide survey of the fields of mycology, parasitism, and fermentation. Needless to say, the task that any President of Section K can at the present time essay must be one of much smaller compass.

In the field of plant pathology which has been so assiduously cultivated of late years, attention has been mainly focussed on the study of the life-history and mode of infection of fungal and bacterial parasites, and on the methods of controlling infection. The relationship of host and parasite

and their mutual reactions have until recently secured but scant attention. It is some of these physiological aspects of parasitism that I propose to take as the subject of my address.

In dealing with any aspect of this branch of Botany one is faced by the fluidity of our conception of parasitism.[1] It may range from the simple relationship to its host of a Sooty Mould or of *Botrytis cinerea* to the complicated relationship found in the Uredineæ.

The physiological aspects of parasitism in the case of a fungus like *Botrytis cinerea* are apparently of the simplest when once it has entered the host. The cells of the host plant are killed in advance by the secretion of an enzyme of a pectinase type and the dead tissues serve as food for the parasite. On the other hand, in the case of the parasitism of fungi belonging to the Uredineæ and Erysiphaceæ (and probably the Ustilaginales, and possibly also the Exoascaceæ) we have a complicated relationship in which there is a definite physiological resistance of the host cells to the attack of the fungal organism. There is action and reaction, the balance of forces sways this way and that—in favour of the host or the invader—and there may for a time be an equilibrium in which the fungus is held in check but not vanquished.

The existence of this reaction between the host and parasite which we find in the Rust Fungi, and which I shall discuss more in detail later, has only been realised comparatively recently, and thus, on the botanical side, the physiological aspect of disease has been largely overlooked. Disease is abnormal physiology, and it is necessarily the result of the interaction of the physiological processes of the host and parasite. This interaction between the physiological processes of the two organisms has long been recognised in animal disease; it exhibits itself in the specific symptoms which are characteristic of disease in man and the higher animals generally. The specific symptoms of such diseases were recognised long before the 'germ basis' of disease was substantiated, and thus the attention of animal pathologists was inevitably turned towards a study of the physiological response of the affected organism. These special reactions are in general so clearly marked that the nature of an infectious disease in man can generally be determined without reference to the invading organism. In plants, on the other hand, the symptoms of parasitic disease are highly generalised, a large number of infectious diseases displaying the same symptoms. It is thus often very difficult, and sometimes impossible, to determine the nature of a plant disease without knowledge of the nature of the parasite. This distinction between diseases of plants and animals is, however, not a fundamental one. The point must be stressed that although the symptoms of different parasitic diseases may be superficially similar, yet the existence of physiological reactions of the host specific for each infection can hardly be doubted when once it is recognised that disease is abnormal physiology, the physiological processes of the host being modified by the physiological processes of the parasite. At the present time we are unable to distinguish the special reactions which the clash

[1] Parasite (παρὰ σῖτος) means etymologically 'beside the victuals.' As Sir Ray Lankester has pointed out, it was the Greek term applied to those attending sacrifices to obtain food. It had no suggestion of meanness till rich men for purposes of display cultivated 'hangers on.' In its primary sense it can be used for any 'co-liver' whether or no it does harm.

of the two sets of processes must produce in the host. With improvements in our methods of biophysical and biochemical analysis we may anticipate a time when these hidden reactions may be revealed and a new basis for the classification of plant diseases established.

Another striking difference between animal and plant pathology which is worth insisting upon is that relating to disease resistance. Disease resistance is shown both in plants and animals, but the particular type of immunity which has been most clearly studied by the workers on the animal side is *acquired* immunity, *i.e.* that type of specific resistance which is the result of one attack of a specific disease. Such immunity must have forced itself on man's attention from very early times, and it is by a study of such resistance that animal bacteriologists—building firmly on the work of Pasteur—have developed the modern treatment of disease by the injection of dead organisms and of the blood fluid of animals containing suitable antibodies. The development of such vaccine and serum therapy should, I think, be rightly considered as one of the most remarkable achievements of modern biology.

On the other hand, the problem of immunity in plants is a far more difficult one than that with which the animal pathologist is faced. The acquired immunity due to one attack of a disease which is so common in animals is unfortunately quite unknown in plants, at least in relation to definite disease. The modern view of recovery from infectious bacterial disease in animals is that it is due to a very well-marked and highly specialised reaction of the invaded organism. Part at least of the reaction is the development of antibodies which neutralise the toxins produced by the invading bacteria and help to bring about their death. It is true that in the Erysiphaceæ and the Uredineæ and in certain cases of endotrophic mycohiza, and in the well-known orchid fungus, the invaded cells show a very marked reaction which may lead to the death, and sometimes to the digestion later, of the invading hyphæ. These, however, are not cases of ordinary disease and the cells show no acquired resistance.

Again, whatever may be the behaviour of individual plant cells when attacked, one never finds that general bodily reaction which is so marked and characteristic of many infectious diseases in the higher animals. The parts of the plants are, of course, much less highly correlated than those of the animal body; there is no circulating blood stream by which the most distant cells of the body can with great rapidity be brought into physiological relationship. Even in the case of the highly specialised parasitism of the Rust Fungi, where there are obvious complex physiological reactions between host and parasite, we find no general reaction by the plant, but cells or small groups of cells carry on a struggle with the invading bacteria and hyphæ apparently in complete independence. It follows that in the absence of any suitable reservoir—such as the blood stream of animals supplies—in which toxins and antitoxins may be sought, the likelihood of their demonstrations, should they be produced, is very slight. The absence in plants of a general bodily reaction to disease would seem also to preclude the possibility of the application to them of serum therapy. If, in spite of the absence from plants of the acquired resistance which is the basis of serum therapy in animals such sera could be prepared, there would be the great difficulty of distributing such substances throughout the plant. Another and apparently insuperable barrier to

success would be the continued development exhibited by the plant, which would necessitate the endowment of the plant body not only with acquired immunity to the disease in question, but an immunity of such a type as would be passed on to the newly developing organs. A reaction of the nature of inherited, acquired immunity would have to be attained, and this in view of the experience of animal bacteriologists is unlikely of realisation.

Immunity and resistance to diseases are, of course, well known in plants, but they are of the nature of *natural* immunity. Plant pathologists need not, I think, reproach themselves for the small progress that has been made in the elucidation of the nature of this resistance, for the basis of natural immunity in animals remains still very obscure, although the physiological field has been worked for a much longer term of years by animal than by plant pathologists.

Some of the processes concerned in the achievement of parasitism in plants may now be considered. The question of the mode of entry of a parasitic organism into a host plant is one of great physiological interest and importance; for a barrier which the would-be invader cannot pass is one of the most obvious means of defence against fungal attack. Apart from entry through wounds, there are two chief modes of entry of the aerial parts of plants, either through a stomatal pore or by actual penetration of the superficial cells of the host. The entry through the stoma, at least in the case of a germ-tube, is clearly the most facile one, and it is somewhat of a biological puzzle that any germ-tubes should follow the hard road of epidermal-cell-penetration rather than the easy path of stomatal invasion where moisture and food material can so easily be obtained.[2] Yet the germ-tubes of *Botrytis*, *Colletotrichum* and *Fusicladium*, for example, and the germ-tubes of the sporidia of Uredineæ, apparently never enter the open stoma but proceed to bore their way laboriously through the epidermis. The case of the Rust Fungi just mentioned is particularly striking, for the germ-tubes of the uredospores and æcidiospores on the other hand invariably enter through the stomata.

The nature of the reaction which brings about the stomatal type of entry is still very obscure. It is frequently assumed that the entry is in response to some hydrotropic reaction, that the germ-tube passing over the stomata finds itself exposed to a stream of water vapour diffusing out of the pore and thus a tropistic reaction is produced. Balls, some years ago, showed that the uredospores of Rust Fungi when placed on a thin perforated sheet of rubber above a water surface developed germ-tubes which passed through the perforations towards the water. This interesting experiment demonstrates that the germ-tubes in question are capable of hydrotropic curvature, but it does not show that the entry into the stoma is due to such a reaction. In the experiment with the rubber sheet there must have been marked differences in the concentration of water vapour on the sides of the membrane. In the case of a germinating spore on the surface of a leaf and under the conditions in which infection usually occurs, the differences in concentration on the two sides must be very slight. The surface of the leaf would be covered with layers of air very nearly

[2] A germ-tube without the capacity for penetration of the epidermis would be at a disadvantage on a non-stomatal surface.

saturated, and the germ-tubes in question are in close contact with the surface of the epidermal cells through which a certain amount of cuticular transpiration is occurring.[3]

The possibility that the entry through the stomata is due to a chemotropic response to some volatile substance (such as a volatile organic acid, aldehyde or ester) emanating from the leaf tissue and diffusing through the stomata ought not to be overlooked. That volatile substances from plant tissues can stimulate or retard germination has been shown by Brown[4] and by Neger,[5] and the ascription by Cooley of 'scald' in apples to the accumulation in closed chambers of acetaldehyde volatilising from the fruit tissue is well known. It would seem also that a positive thermotropic reaction ought not to be overlooked in considering the physiological aspects of fungal penetration of the host. Penetration of the surface of the leaf by a germ-tube occurs under conditions of high humidity and very slight air movement, conditions which would tend to reduce the heat losses of the leaf to a low level. In such circumstances the respiratory processes of the tissue might easily be responsible for a leaf temperature of the order of 1° C. above that of the air.[6] The penetration by germ-tubes of such surfaces as those of gelatine and collodion show, however, that this cannot be a main factor.

The question of the physiological processes concerned in the other method of entry, that through the epidermal cell, also requires further elucidation, and the conditions surrounding a germ-tube developing in a drop of water on a leaf may be considered. When the work of Miyoshi on the chemotropism of fungi and of pollen tubes appeared in 1894, it was naturally assumed that entry was due to a positive chemotropic response of the germ-tube or fungal hypha to some substance diffusing from the surface cells of the host into the drop containing the germinating spores. Considerable doubt, however, was thrown on the interpretation placed by Miyoshi on his results by the work of Clarke and of Fulton, who demonstrated that fungi showed a marked negative chemotropism to their own waste products. It remained questionable then as to whether fungi exhibited any positive chemotropism towards nutritive substances. Graves,[7] however, by allowing for the negative chemotropism towards staling products and giving it a rough quantitive measure, was able to show that, in addition to this negative reaction, there is a definite positive reaction towards such substances as cane sugar and turnip-juice. A tropism of

[3] The cogency of this argument is reduced by the fact that the same difficulty arises in the case of all chemotropic reactions. The differences in the concentration of a sugar on the two sides of a hyphal tip, which responds to a diffusion gradient by a curvature, must in many cases be exceedingly small. It seems possible that in all such cases other factors may be at work.

[4] W. Brown, 'Studies in the Physiology of Parasitism IX.' *Annals of Botany*, xxxvi., 285, 1922.

[5] F. W. Neger, 'Förderung der Keimung von Pilzsporen durch Exhalationen von Pflanzenteilen.' *Naturw. Zeit. f. Land- u. Forstwirtschaft*, ii., 484, 1904.

[6] For the latest leaf-temperature measurements of crop plants see E. C. Miller and A. R. Saunders (*J. Agric. Res.*, XXVI., 15-43, 1923), who have made 20,000 observations of such temperatures. Except in direct sunlight and in wilted leaves they find only slight differences between the temperature of the air and of the leaf, but, as stated above, the conditions suitable for infection are of a special kind.

[7] A. H. Graves, Chemotropism of *Rhizopus nigricans*. *Botan. Gazette*, lxii., 337, 1916.

this kind seems, however, insufficient to explain the reaction of germ-tubes towards the surface of a host plant. The germ-tubes of *Botrytis* developing in a drop of turnip-juice will penetrate the surface of a bean leaf; and as the turnip contains substances which strongly attract germ-tubes (at least those of *Rhizopus*), it seems unlikely that the concentration of any attractive substances which may diffuse through the cuticle would be sufficient to produce a stronger response than that due to the comparatively high concentration of the active substances in the drop. Again, Dr. Brown has shown in an unpublished observation that germ-tubes of *Botrytis* growing in turnip-juice will penetrate a thin sheet of paraffin (about 10 μ in thickness) which is floating on the same fluid. In such cases where a positive chemotropism appears very unlikely, the only other possible reactions which might be at work seem to be a negative chemotropism of the germ-tubes towards its own waste products, or a positive reaction towards the surface with which the germ-tube is in contact. If such a negative reaction were the main factor in penetration, one would expect the germ-tubes of any fungus, such as *Penicillium* or *Rhizopus*, to enter a bean leaf from turnip-juice; this, however, does not occur. Furthermore,

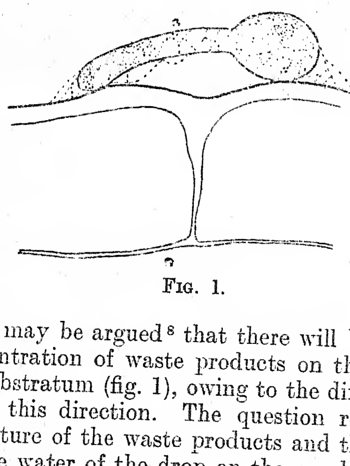


Fig. 1.

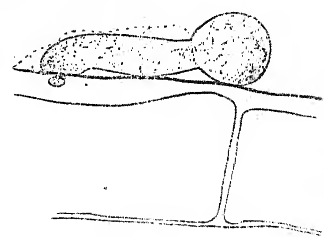


Fig. 2.

it may be argued[8] that there will be a higher rather than a lower concentration of waste products on the side of the germ-tube towards the substratum (fig. 1), owing to the difficulty of the escape of such products in this direction. The question really resolves itself into that of the nature of the waste products and their relative rate of diffusion through the water of the drop on the one hand, and through the epidermal cell-wall on the other. If the waste products can diffuse with fair rapidity through the cuticle and epidermal cell-wall and so escape into the general body of the leaf, or if they are taken up in some way (possibly by adsorption) by the host cells, then it is quite possible that the concentration on the lower side towards the host tissue may be such as to lead to a growth towards that host surface. The probability of a negative chemotropism of this kind playing any considerable part in the responses of the germ-tube which lead to penetration does not, however, seem very strong. Such a chemotropism certainly does not prevent the germ-tubes of such fungi as *Botrytis* and *Colletotrichum* fixing themselves firmly to an impermeable glass surface.

If both positive and negative chemotropism are excluded it would seem that a contact stimulus must play the major part in the entry of a parasite

[8] As Dr. W. Brown has suggested to me.

into the epidermis of the host. This response to contact with a solid substratum is usually termed thigmotropism, though stereotropism would seem to be the more satisfactory term. That the germ-tubes and hyphæ of many fungi (such as *Botrytis*, *Colletotrichum*, *Sclerotinia Libertiana*) exhibit a stereotropic response is, of course, easily demonstrated by growth of such fungi in hanging drops on a glass surface. The question then arises as to whether stereotropism is the sole or main cause of the growth response which leads to entry. If a tropism of this kind be the main factor, one would expect the penetration of any surface (such as a leaf) of not too great resistance by any germ-tube responding to a contact stimulus, *i.e.* an entry quite non-specific.[9] At present the data available do not seem sufficient to answer this question. The problem of the mechanism of infection requires investigation from this particular angle. Some light on the matter could no doubt be obtained by germinating together the spores of two parasitic fungi, say A and B, first on the host of A (which B does not infect), and then on the host of B (which A does not infect), and comparing accurately their responses on the two substrata. It is the melancholy experience of physiological work that a simple explanation of any process is almost certain to be wrong. It would therefore seem unlikely that stereotropism alone is responsible for penetration. How complex is the relationship is shown by another observation of Dr. Brown's that germ-tubes of *Botrytis cinerea* are unable to penetrate the epidermis of an uninfected leaf of *Eucharis amazonica*, but they will bore through it when the mesophyll tissue below is cut away, even when the leaf so treated is 'backed' with agar.

The question of the actual mechanism of entry is of considerable physiological interest. A number of studies by Brown, Blackman and Welsford, Boyle, and Dey[10] have been published which bring forward evidence for the view that the entry of a germ-tube through the cuticle of the host is a purely mechanical process in which enzymes play no part. The evidence for this is in part directly observational. When the process of entry is carefully followed in such forms as *Botrytis cinerea*, *Colletotrichum*, *Sclerotinia Libertiana*, the sporidia of *Puccinia graminis*, it is found that the germ tubes or appressorea become firmly attached to the surface of the host before entry, and no swelling of the cuticle can be observed prior to entry. Furthermore, entry is usually by a very fine infecting hypha (fig. 2), and at the actual point of entry of such hypha there is no rounding of the contours of the cuticle as we should expect if enzymes were at work. There is also the additional point that no enzyme is known that is able to dissolve cuticle. The injection into an organ, such as a leaf, of an extract of the germ-tubes of *Botrytis* is a very convenient way of preparing sheets of cuticular material. The resistance of cuticle to bacterial attack is well shown by the composition of brown coal, which often consists very largely of cuticular material.

If the germ-tube is to exert sufficient force to bore its way through the

[9] In the case of the Uredineæ the entry through a stoma is quite non-specific, for, as Miss Gibson showed, the germ-tube of almost any Uredine will enter the stoma of almost any leaf, but the establishment of parasitism depends upon the suitability of the host.

[10] 'Studies in the Physiology of Parasitism.' *Annals of Botany*, xxix.-xxxv., 1915-1921.

resistant cuticle, it is evident that it must have some *point d'appui* against which the force can be expected. There must clearly be some adhesion of the germ-tube to the substratum or else the development of an outgrowth from the germ-tube will result, not in penetration, but merely in the forcing the tube away from the surface. It was originally suggested [11] that the gelatinous sheath which can be demonstrated round the germ-tubes of *Botrytis cinerea*, and of some other parasitic fungi, is the main factor in the close attachment of the tube to the substratum. Further consideration, however, suggests that the essential preliminary to penetration is the close adhesion of the tip of the germ-tube to the surface to be penetrated. This close adhesion to the surface to be penetrated is a constant feature of epidermal infection, whether we are dealing with *Botrytis cinerea*, *Sclerotinia Libertiana*, *Puccinia graminis* (sporidia), or the case of *Colletotrichum* where the tip of the germ-tube becomes converted into a dark-coloured, thick-walled appressorium from which the infection-tube grows out later. In this adhesion the two gelatinous sheaths may play some part, but when one considers the ' microscopic ' closeness of the contact it would seem clear that molecular forces must be at work, so that once they are brought into such close relationship the two surfaces would necessarily adhere.[12] This sheath may, however, be of use in preventing the germ-tube from being easily washed off the surface on which it is growing and also in giving the germ-tube the attachment necessary if the tip is to be pressed firmly against the surface of the leaf or other organ. Once, however, the two surfaces are pressed together they should adhere in the manner indicated.

It will be noted that the adhering surface from which the infection tube grows out is in general large compared with the cross section of the actual peg-like infection hypha which bores through the cuticle (fig. 2). This hypha is very small, and in the case of sporidial infection in *Puccinia* and infection by *Synchytrium endobioticum* it is of extreme tenuity, so that in the epidermal wall itself it can only just be observed. The absolute pressure required to push such a minute infection hypha through the wall would be very small, and the forces of adhesion which hold the tip of the germ-tube (or the body of the zoospore in *S. endobioticum*) to the surface of the host cell would seem to be more than sufficient to resist the *back* pressure resulting from the outgrowth of the infection tube. The processes concerned in the development of this outgrowth are probably very similar to those concerned with the development of a lateral branch on a hypha. If one assumes that the cell-wall of the germ-tube becomes softened over the appropriate area, then the osmotic pressure of the contents of the germ-tube should be more than sufficient to overcome the resistance of the cuticle and the sub-cuticular layers of the cell-wall. It is interesting to note that Hawkins and Harvey conclude that mechanical puncture is the method by which *Pythium debaryanum* passes after entry through the ordinary cell-walls of the potato tuber,[13] and that resistance of the tuber cells to mechani-

[11] Blackman and Welsford, 'Infection by *Botrytis cinerea*.' *Annals of Botany*, xxx., 389, 1916.

[12] This suggestion that such molecular forces come into play was originally put forward in a discussion by Dr. A. L. Balls.

[13] L. A. Hawkins and R. B. Harvey, 'Physiological Study of the Parasitism of *Pythium debaryanum* Hesse, on the Potato Tuber.' *J. Agric. Res.*, XVIII., 275, 1919.

cal puncture and resistance to attack by this fungus are definitely correlated. These authors also determined by plasmolysis the osmotic pressure of the fungal hypha and the pressure required to perforate the tissues, and they found that in all cases but one the osmotic pressure was sufficient to allow of puncture of the wall of the potato cell by the hypha.

The question of the nutritive conditions to which the germ-tube is exposed when developing on the host tissue is evidently of importance in infection. A strong well-developed germ-tube is more likely to succeed in penetrating the host tissues than a weakly one. This is in agreement with the experience that with forms like *Botrytis* and *Colletotrichum* it is easier to get infection from drops of weak culture medium than from water. In nature, however, the 'infection drop' must usually consist of rain or dew. That substances which are able to stimulate the growth of the germ-tubes can diffuse from the underlying host tissue into the infection drop has been shown by W. Brown (*loc. cit.* 1916). How considerable may be the amount of substances diffusing into water on the surface of a plant is shown by the analysis of dew from cotton plants given by Smith. No less a quantity than 1,300 c.c. was collected, and it was found to have a content of total solids of 1,023 parts per million, most of the solids consisting of calcium and magnesium carbonates.[14]

The observations of R. J. Noble on Flag Smut of wheat (*Urocystis tritici*) provide another example of the stimulating action of minute amounts of tissue extracts. The addition of a few thin slices of wheat tissue to water in which well-soaked spores of this fungus are lying increases very markedly the amount of germination over that in ordinary culture media. The action is not specific, for tissues of rye, barley, flax, etc., will produce the same effect, though to a less degree. The distillate from watery extracts of wheat seedlings was also found to act, so the stimulating substance is volatile, and possibly similar to the substances observed by Brown, to which reference has already been made.[15]

It is clear from such observations as these that the conidium may find in the infection drop on the leaf a supply of nutritive or stimulating substances. Of the chemotropic power of these substances there may be some doubt, but of their importance in the production of vigorous germ-tubes well equipped for the work of cell-wall penetration there can be little question. In the study of the mechanism of entry by various fungi into the epidermal tissues of their host undertaken by the writers already mentioned, not only was there no evidence of solution of the cuticle, but until the cuticle had been ruptured there was no sign of enzymatic action on the cell-wall layers beneath. This suggests that cell-wall dissolving enzymes are unable to diffuse through the cuticle. It should be pointed out, however, that Smith,[16] in his study of the haustoria of the Erysiphaceæ, describes a change in the staining reaction of the cell wall below a hypha before the cuticle had been ruptured. Miss Allen also describes a marked

[14] C. M. Smith, 'Excretion from leaves as a Factor in Arsenical Injury.' *J. Agric. Res.*, XXVI., 191-4, 1923. The analysis in full, in parts per million, was S_1O_2, 13; oxides of Iron and Aluminium, 17; SO_3, 26; Cl, 19; CaO, 529; MgO, 100; CO (by titration), 618.

[15] R. J. Noble: 'Studies on *Urocystis tritici* Koern, the Organism causing Flag Smut of Wheat.' *Phytopathology*, 13, 127, 1923.

[16] G. Smith: 'A Study of the Haustoria of the Erysiphaceæ.' *Bot. Gaz.*, 16, 1905.

change in the cell walls of the guard cells lying below the appressorium of *P. graminis tritici*. These guard cells had not been penetrated, the hypha passing between them to form the substomatal vesicle, and yet the walls of these cells became markedly altered in their reaction to stains. It may be that both these cases demonstrate the action of enzymes derived from the fungus, for diffusibility and non-diffusibility are only questions of degree; it may be, on the other hand, that these cell-wall changes are due to changes produced in the host cell as a result of the entry into the cell of poisonous fungal products more diffusible than are enzymes.

The question may now be considered as to what progress has been made by plant pathologists in elucidating the quality of natural immunity? As has already been stated, the problem of natural immunity is an extremely difficult one which animal pathologists on their side have found very baffling. It can be said, however, that some success has been achieved in a preliminary analysis of some cases of natural disease resistance in plants. As is so common in biological work, the difficulty of solution is greatly enhanced by the variety in the types of disease resistance. In many cases resistance to disease is achieved by keeping the enemy out by some physical barrier, or possibly by some special chemical environment in the absence of such a barrier. In other cases the parasite achieves entry and in a susceptible host makes its way through the tissues comparatively unimpeded, while in a resistant the entry calls forth a wound reaction leading to the production of cork which hinders or sets a complete bar to the progress of the invader. A good example of these two types of behaviour is that of *Fusarium Lini* when attacking susceptible or resistant forms of flax. In one case the physiological processes of the resistant host interacting with those of the fungus lead to abundant cork-formation; in the other they do not. In what manner the physiological processes of the two types of host differ we cannot at present say. Nor can we at present explain why the harmonious relationship, which in the case of the cereal Smuts is established for most of the vegetative life of the host, suddenly breaks down on the development of the inflorescence. Is the metabolism of the cells of the developing reproductive organs so markedly different from that of the meristematic cells that the fungus is stimulated into active development and parasitism? It would seem likely that a further knowledge of the nature of the 'physiological gradients' between the parts of plants would throw some light upon the peculiar relations of host and parasite in the cereal Smuts.

How elusive may be the factors underlying resistance is exemplified by the observations of Walker [17] on Onion Smudge due to *Colletotrichum circinans*. He found that onion bulbs with coloured outer scales were usually highly resistant, while white varieties were in general susceptible, and, furthermore, a watery extract of dry outer scales of the coloured onions is a marked toxic to the spores and mycelium of the fungus. On further examination it was found that although the internal white scales can be infected with ease, yet an extract of these inhibits the germination of the conidia and also retards the development of the mycelium. The volatile 'onion oil' seems responsible for the inhibition and retardation, yet when the fungus is growing in the host tissue there is no such action.

[17] J. C. Walker, 'Disease Resistance to Onion Smudge.' *J. Agric. Res.*, XXIV., 1019, 1923.

It is only in the Erysiphaceæ and Uredineæ that we have knowledge of any cell reactions (though not of any general reaction of the plant body) comparable with those occurring in the infectious diseases of the higher animals. In these two groups the phenomenon of so-called specialisation of parasitism is well marked, and it is a comparative study of the behaviour of the biologic forms of the parasite on susceptible and resistant hosts that has been most fruitful. As has been known for some time, the normal relation of host and parasite in the mildews and rusts is, in the early stages of infection, one in which the fungus develops at the expense of the host cells; these, however, are not killed but stimulated to active development. De Bary observed long ago that the mildewed leaf may retain its green colour longer than the uninfected one. Salmon observed some years ago that the conidia of *Erysipha graminis* when growing on other than their normal host might send down haustoria into the epidermal cells, but such absorbing organs were short-lived. Neger[19] has recently investigated more closely the result of sowing upon the leaves of *Hieracium* of the conidia of *E. Cichoracearum* from *Sonchus asper*. The germ-tubes send into the epidermal cells outgrowths which start to produce haustoria. In contrast with infection of the normal host, the cells react markedly; they become filled with a gum-like mass which encapsules the haustoria. The epidermal cells then loose their turgor, die, and the development of the fungus is stayed. A leaf sprayed with suspension of such conidia appears as if it had been sprinkled with minute drops of a corrosive fluid. However, it is in relation to the cereal rusts that we have the clearest picture—in its purely superficial aspects at least—of the nature of resistance. With the discovery by Professor Biffen that resistance to the attack of *Puccinia glumarum* was associated with a single mendelian factor, attention was naturally turned to the question of the nature of this resistance. Miss Marryat, comparing in Professor Biffen's laboratory the susceptible Einkorn and the resistant Michigan Bronze wheats, made the surprising discovery that the resistance was in one sense no resistance at all.[20]

The variety Einkorn was not able to keep the parasite out, for the hyphæ attacked the mesophyll cells, but the invaded leaf-cells—instead of establishing an harmonious working relationship with the mycelium as with Michigan Bronze—react very strongly, with the result that both they and the invading hyphæ are killed. The course of infection is thus stayed as a result of this *hypersensitiveness* of the host. The result with *P. glumarum* was later extended to *P. graminis*. The striking and assiduous work of Stakman and his co-workers has revealed to us that even *P. graminis* forma *tritici* consists of twenty or thirty different strains with a widely varying range of susceptibility and resistance among the different varieties of wheats. Stakman* in 1915 was able to confirm the violence of the reaction when strains of this form are sown on a resistant host; hypersensitiveness here also is the key to resistance. Last year

[19] F. W. Neger: 'Mehltaupilze—eine Art von gedultete Symbiose.' *Flora*, CXVI., 331, 1923.

[20] D. C. E. Marryat: 'Notes on the Infection and Histology of two Wheats immune to the attack of *Puccinia glumarum*.' *J. Agric. Science*, II., 129, 1907.

* E. C. Stakman: 'Relation between *Puccinia graminis* and Plants highly resistant to its attack.' *J. Agric. Res.*, V., 193, 1915.

Miss Allen [21] published a very careful and detailed cytological study of the infection of susceptible and immune wheats by forms III. and XIX. of *P. graminis tritici.* Mindum wheat is immune to form III. and Kanred to form XIX., so the behaviour of these two wheats was compared with that of other susceptible varieties. When Mindum is infected with the uredospores of form III. an appressorium is formed over the guard cells and entry occurs in the normal way through the stoma. Usually the first haustorium from the infection hypha develops in a mesophyll cell and its formation is the signal for a violent reaction on the part of this cell. The host-cell contents, including the cytoplasm, nucleus and plastids, flow rapidly towards the haustorium and become massed around it, forming apparently a sheath to the haustorium. Of the haustorium and host-cell cytoplasm Miss Allen states 'each seems to be toxic to the other ; at least, both die very soon.' The haustorium and its cytoplasmic sheath appear to be partially digested. The infection hypha is not killed by this reaction to the first formed haustorium, but only checked ; it may develop a few other haustoria in other host cells which are similarly killed ; finally the limited resources of the hypha are exhausted and it succumbs.

From a single infection only a small number of cells, about five or six, are killed by being entered directly by the fungus. The 'fleck' visible to the naked eye which is the sign of an attack successfully repelled consists of a much larger number of dead or damaged cells. This is explained by the fact that the violent *primary* effect due to entry is followed by a mild *secondary* effect on the cells surrounding the area of cells killed by entry. These neighbouring cells in a region 3-4 cells deep become plasmolysed and shrunken, and some of them show marked swelling of the walls.

Although in the cereal rusts we have the most complex reaction to attack by an invading organism which has been observed in plants, we find very few phenomena analogous with the response to infectious disease of higher animals. When the susceptible forms are attacked we find no spontaneous cure, no recovery of the attacked cells. We have no evidence in the resistant forms of the productions of antibodies in either the susceptible or resistant forms ; the death of the haustoria may be simply due to the death of the host cells in which they lie. It is true that we have a digestion of the haustorium, but this 'phagocytosis'—since the digestion of the haustorium is associated with the digestion of the host-cell contents and takes place after the death of that host cell—may be nothing more than an effect of autolysis.[22] Again, no general bodily reaction of the plant is apparent, each infection is highly localised, and each group of host cells fights a solitary battle independent of its neighbours. No analysis of plant resistance on the lines found so successful in animal disease can be achieved at present, nor is it likely in the future in view of the

[21] R. F. Allen : 'Cytological Studies of Infection of Baart, Kanred and Mindum Wheats by *Puccinia graminis tritici.*' *J. Agric. Res.*, XXVI., 571, 1923.

[22] It is true that in such peculiar symbiotic relationships as those of the orchid fungus and endotrophic mycorhiza—cases which do not fall into the category of ordinary disease—we do find digestion of invading fungal hyphæ by living active host cells. Such cells are, however, far from acquiring any resistance by such phagocytosis, for it has been observed both in orchids and in mycorhiza that host cells which have successfully coped with one attack by the process of digestion may be invaded again (*vide* Rivett, *Annals of Bot.* XXXVIII., 1924).

marked dissimilarities between the two. As has already been insisted upon, the immunity which has to be explained in plants is *natural*, while that resistance which animal pathologists have explained, at least in part, is *acquired*. The explanation of the difference in the behaviour of the mesophyll cells of the susceptible and resistant wheat must lie in the difference in the normal physiological processes of the two. This demonstrates how dependent is plant pathology for its advance on plant physiology. The differences do not seem to be merely differences specific to the wheat varieties, differences such as would be common to all the cells of the plant—or if there are such differences they are easily masked by other factors—for Miss Allen observed that while the mesophyll cells of the resistant wheat reacted violently when invaded, yet if an epidermal cell was attacked the haustorium developed might attain its full size and function for some time. It is evident that we must await fuller knowledge of the normal physiological processes of the cells of the two varieties, and of the physiological differences between the cells of different tissues, before much light will be thrown on the nature of such immunity as is met with in the Erysiphaceæ and Uredineæ.

A consideration of the nature of disease resistance in plants thus leaves us with no expectation of finding means for endowing plants with artificial disease resistance. Apart from the protection of plants from infection by the use of fungicides, etc., our chief hope of combating disease lies in two directions—one, that of breeding disease-resistant forms of plants, and the other that of the enhancement of the natural resistance of the plant. In breeding for disease resistance, marked successes have been obtained since Biffen's fundamental work on mendelian inheritance of resistance to *Puccinia glumarum*. In a number of cases of rust resistance in cereals since examined, immunity has been found to be dominant over susceptibility. The question of breeding wheats resistant to *P. graminis*, which is, of course, one of great economic importance, has been much complicated by the discovery, to which reference has already been made, that a very large number of biologic forms or strains of *P. graminis tritici* exist; high resistance to attack by some of the strain may be associated with marked susceptibility to attack by other strains. Aamodt, however, claims to have demonstrated that it is possible to build up synthetically a wheat which will be resistant to a large number of biologic forms of *P. graminis tritici*.[23]

Although we find that the field of control of plant diseases by substances lethal to fungi and by the breeding of disease-resistant host plants is being actively cultivated at the present time, yet the field of inquiry as to the effect of environment on the liability of plants to diseases is comparatively unworked. The view that immune plants, such as cereals immune to rust, might suddenly lose their resistance under new conditions is now no longer held; the apparent loss of resistance is probably in part explicable by the fact that the host in its new environment has been subjected to attack by another biologic form of the fungus than that to which it is resistant. In spite of this, however, it is perfectly clear that with numerous diseases the degree of natural resistance is markedly affected by the conditions of

[23] O. S. Aamodt: 'The Inheritance of Growth Habit and Resistance to Stem Rust in a Cross between Two Varieties of Common Wheat.' *J. Agric. Res.*, XXIV., 457, 1923.

cultivation. In some classes of disease, such as the Rusts, the intensity of attack tends to rise with the increased vigour of the plant, and Melhus [24] found that with unhealthy plants it was almost impossible to obtain satisfactory infection by *Cystopus candidus*.

On the other hand, there is a large class of infectious diseases in which the degree of natural resistance can be markedly enhanced by good cultivation. Under good conditions such diseases, which with Nowell [25] may be termed 'Debility diseases,' are of little importance; they only become serious when the crops are growing under unfavourable conditions. Diseases of this class are usually caused by saprophytes which are only weakly parasitic. The question of the nature of the changes occurring in the plant in conditions of so-called debility are quite unknown. The problem is sure to be a complex one, but it is possible that one of the factors may be an increased permeability of the superficial tissues of the less vigorous plants, so that the spores on the surface of the host find conditions especially favourable for vigorous growth. In addition to the relation of general health to the incidence of certain plant diseases, we have the undoubted effect of certain fertilisers, such as potash, in reducing the intensity of fungal attack. Exploration of such fields of physiological research, though no doubt the difficulties of investigation are considerable, should certainly provide results of great scientific interest. A clue to the nature of the changes occurring in plants which can reduce their liability to disease may also open the way to the enhancement of natural resistance by other and possibly more economical ways. Clearly it is on plant physiology that plant pathology is largely dependent, not only for the elucidation of the relationship of host and parasite, but also for fundamental scientific knowledge which may profoundly affect economic practice.

[24] J. E. Melhus: 'Experiments on Spore Germination and Infection in certain Species of Oomycetes.' *Wisconsin Agr. Exp. Stat. Bull.*, 15, 1911.

[25] Nowell: 'Diseases of Crop Plants in the Lesser Antilles.' 1923.

SECTION L.—EDUCATIONAL SCIENCE.

THE NATURE AND CONDITIONS OF ACADEMIC FREEDOM IN UNIVERSITIES.

ADDRESS BY
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PRESIDENT OF THE SECTION.

Freedom, in that sphere of politics in which we use the word most often, may be an attribute either of the individual, in his thought and action within the community, or of the community itself, in its relations and standing among other communities. It may be a right of the citizen, or it may be an attribute of the State. In the intellectual sphere, with which we are here concerned, freedom may similarly be an attribute either of the individual teacher, in his teaching and speaking and writing, or of the whole academic community, in its relation to the general environment of political authorities and economic interests in which it is set. These two freedoms of the mind are almost correlative. We may almost say that a free professoriate means a free academic community; and, conversely, that a free academic community means a free professoriate. But there are qualifications and limitations of this identity. A university which is free from control by the general social environment may seek to control unduly its own professors in the name of its own alleged freedom. We cannot, after all, treat academic freedom under a single head; and in any discussion of the subject we must distinguish the freedom of the teacher from that of the university.

The freedom of the teacher, like all freedom that is other than mere license and anarchy, must exist within a framework of law, because it exists within the framework of an institution, and because, again, any institution involves some system of law. The law of an academic institution is partly an unwritten code of professional conduct, and partly, it may be, a written set of principles and tenets. The unwritten code forbids a teacher to use his class-room as a place for the inculcation of partisan views. It may be difficult to draw a clear line of division between what is partisan and what is impartial; but we should all agree that there *is* a line, and that, in his class-room, a professor is not free to wander on the further side of that line. What he may do outside the class-room is another matter, which we must consider later. A written set of tenets and principles is comparatively rare; but it may obviously exist, for example in a theological college or a general college founded on a confessional basis. A professor who has subscribed to these tenets has voluntarily limited his freedom by that subscription. The college to which I belong at one time required a written subscription from its teachers to the Thirty-nine Articles.

When F. D. Maurice was deprived of his chair, in 1853, for his views on eternal punishment, it was not definitely stated in the resolution of the governing body that he had contravened those Articles. It was stated, in vaguer terms, that his opinions were 'of dangerous tendency . . . calculated to unsettle the minds of the theological students . . . detrimental to the usefulness of the college.' None the less, though the action taken by the governing body was not grounded, and perhaps could not have been grounded, on a definite contravention of the Thirty-nine Articles, the existence of a rule of subscription to those Articles was the real basis of that action.

A much more difficult question arises when we turn to consider the action of a professor outside his class-room. Here, again, the case of F. D. Maurice occurs to the mind. He was attacked in 1851, and virtually censured, though not deprived of his chair, for his connection with the Christian Socialist movement. The case is curiously typical, and curiously apposite to our modern difficulties, even though it occurred over seventy years ago. Croker had launched the attack in the Press, and besides attacking Maurice he had drawn the college into the issue, by stating that 'it added to his surprise to find the holder of such views occupying the professorial chair . . . in King's College, London.' Some general considerations of a large pertinence are suggested by Croker's action and words. The Press *may* defend, and by its own position as a natural champion of freedom of expression of opinion it will often actually defend, the freedom of a professor; but just because it is necessarily set on publicity, it is also a danger to that freedom. It does not help the free course of thought that its delicate difficulties should be cried in the streets. The Press, again, will always attach the label 'professor,' and the name of his institution, when it chances to mention in any connection an ordinary citizen who is also a professor at any institution. By such attachment a sad result is entailed. If the citizen who is also a professor speaks on a public issue, he is made to involve his institution in what he says. If what he says is unpopular, he may make his institution unpopular: it may lose students: it may lose benefactions.[1] What is the institution to do? Should it make a rule, such as the Principal of King's College seemed to suggest in 1851, 'that you will do your utmost to bear in mind the duty and importance of not compromising the College'? If it makes such a rule, it will be bound to define what is compromising, and it will be bound in the last resort to enforce its definition. In order to prevent itself from being compromised, it will compromise itself terribly. A professor may compromise it in part: it will compromise itself as a whole. A wise president of a great American University—President Lowell of Harvard—has put the point admirably in his annual report for the Session 1916-1917: 'If a University or College censors what its professors may say . . . it thereby assumes responsibility for that which it permits them to say. This is logical and inevitable, but it is a responsibility which an institution of learning would be very unwise in assuming.' A wise university will run any risk of being compromised by its members rather than compromise its entire self.

But if the university is wise to tolerate, the professor is wise to be severely moderate and master of himself. It is true that he is a citizen,

[1] This is stated, or implied, by the Principal and Council of King's College in 1851. See the *Life of F. D. Maurice*, by F. Maurice, ii., p. 80, p. 98, p. 101.

and has every right of an ordinary citizen—engineer, lawyer, doctor or banker—to express his opinions on civic affairs. It may even be urged that he has a special right to express himself, in virtue of the possession of special knowledge; and it is possible to contend that he has even a duty to aid the judgment of the community by contributing his knowledge and his opinion in vexed questions which lie specially within the ambit of his chair. A professor of Spanish, for example, may hold himself bound to instruct the public opinion of his community on Spanish affairs, and even to suggest the adoption of a definite attitude by his fellow-countrymen in relation to such affairs, if they have become the question of the hour, pregnant with issues of peace or war, and if he has a knowledge which has not yet been attained by publicists, journalists, and other such guides of public thought. On the other hand, it is a pity that a professor should become a publicist except in the gravest emergency. It is difficult to be at once a publicist and a scholar; and a professor is primarily a scholar. Here we touch a fundamental consideration. A professor is a citizen, with the general rights or obligations of a citizen: he is also a member of a profession, with the special obligations of that profession. Herein he is like the doctor or lawyer, who have also their special obligations, as, for example, the obligation of secrecy in regard to the affairs of their clients. The special obligations of the professor, which are contained in the unwritten code of which we have already spoken, are less definite than those of the doctor or lawyer; but they are there. He has embraced a profession devoted to the dispassionate search for pure truth. He seeks truth for truth's sake by a rigorous method of inquiry. The temper of his mind must be steeled into a resolute disposition to see every side and to weigh every factor. He is training young minds: what he is, and what he does, affects the growth of those minds, just because the attitude, the temper and the method of the teacher are always a suggestive force to the young, and are always, however unconsciously, in virtue of that law of imitation which sways so strongly all our minds, the fountain and source of a like attitude, temper and method among the taught. If there is a discipline which is a special obligation of the soldier, there is also a discipline which is a special obligation of the professor who serves under the banner of truth. To see, and to show to others, the six sides of a square question: to amass every relevant fact, and to leave no fact unverified: to shun the limelight of publicity, because it distorts and is not the clear light of truth: not to lend knowledge to the service of a one-sided cause, or to divulge research in aid of a journalistic 'scoop'—all these are parts of the discipline. At the same time, the professor must be a man, and not an automaton. He may become the latter, if he is purely and solely of the laboratory. Some measure of outside interest and outside work is a condition of vitality and even of balance. Without it he may be anæmically academic, and lose himself in an exaggerated sense of the sovereignty of his subject. F. D. Maurice was not in error when he said of his colleagues that 'their classes in the college, I believe, are infinitely the better for their labours and studies out of it.'[2]

There are certain subjects in which the freedom and the duty of a professor raise specially difficult problems. They are the subjects of history, government and economics—to which we may perhaps add the

[2] *Op. cit.*, ii., p. 85.

subject of modern languages, when the professor of such a subject concerns himself, as it is good that he should, not only with the language and literature, but also with the history and contemporary civilisation of the nation with which he is concerned. If the cause of academic freedom was fought in the past on the ecclesiastical field, and in regard to chairs of divinity, it is likely to be fought in the future on the field of politics and economics, and in regard to the chairs which touch those subjects. A professor of such subjects cannot stop short of running into the actualities of the present. If he were required to do so, he would be stopped from reaching what we may almost call the point of fertilisation, where his knowledge touches actual life. I would not say that the history of the past is the guide to the solution of the problems of the present; I would rather say, with Croce, that all history is contemporary history, and that the historian explains what we are by showing to us the living past which makes our present life. Even on that basis, the present is the concern of the historian, as it is also, for that matter, of the teacher of political theory, or of economics, or of modern languages. The teachers of all these subjects are handling and interpreting the present. They move in a region of very special difficulty and very special obligation. They handle the live stuff of which actual political and economic questions, national and international, are made. *Incedunt per ignes.* They may write to the *Times* on current questions, according to our English habit, which has no doubt its American equivalent; they may publish pamphlets and books on current questions; they may even (and this raises desperate difficulties) become parliamentary candidates. I cannot deprecate the trend of these subjects and of their teachers in modern universities towards what I may call actuality. At the same time, I cannot but register the difficulties to which it leads. Public attention may be drawn to a university which has become a live coal, and public criticism may fasten on its burning. What is more, a number of interests may interest themselves in controlling the manner of its burning. Universities are always in need of endowment. A benefactor, or a group of benefactors, may be very ready to found a chair—and that possibly a chair of a certain complexion—in a subject of history, or of politics, or of economics, or of the language, literature and civilisation of a given nation. If the professor is conformable to their expectations, all may be well—from one point of view. If he is not—*surgit quaestio.* But this difficulty belongs rather to the topic of the freedom of the whole academic community, and that belongs to another and later inquiry. Here we are concerned with the freedom of the individual professor. So far as that freedom is concerned, I can only repeat, with some qualification and extension, the conclusions I have already tried to state. My general principle is freedom, uncontrolled by any assumption of responsibility by the university, which is likely to run more danger thereby than can ever be involved in any possible indiscretion which a professor may commit in the use of such freedom. My qualification of that principle is two-fold. In the first place, the freedom of the professor is subject to the discipline of the profession, which commands him to seek the truth, the whole truth, and nothing but the truth. If he cannot submit himself with all his heart to that discipline, he had better quit the profession and become a politician or a journalist. In the second place, the freedom of the professor, while it is not subject to the control of the institution to which he belongs, must

at any rate be qualified by the duties inherent in his membership of that institution. If it gives him freedom, he must not give it obloquy in return. He will be wise, in many cases, to say, and to say very clearly, that he speaks in his own name, as a private citizen, without any warrant from his institution, or any power to bind or conclude his institution in any way by what he says. But I do not think that a professor will ever go far wrong if he submits himself to the discipline of the profession. The great safeguard of true professorial liberty is simply a stern sense of the sanctity of the academic vocation, cherished among all its members, and enforced by all its members through the sanction of disapproval against an erring colleague. What we need is the elaboration by the professors themselves, and the enforcement by the professors themselves, of a code of professional conduct. Here at any rate, without any subscription to the tenets of guild socialism, and without any confession to a creed of the government of the teaching profession by itself, one may see a field for professional self-determination. It is not exactly an easy thing. Some professors, of a conservative cast of mind, will always frown upon their colleagues who are hardier, even when they walk within just limits. Others, of more radical propensities, will always smile upon a bold colleague, even when he has obviously overshot any conceivable mark. But if the thing be difficult, it is none the less needful.

I turn to consider, in conclusion, the broader theme of the freedom of the whole academic community. The mediæval university, as its very name implies, was a free guild of teachers, or sometimes of teachers and scholars. It was not subject to any local authorities (there were none, and anyhow it was not local); it was hardly subject to the State, for the State was a loose federal sort of body, which left all guilds pretty much to their own devices; it *might* be subject to the Pope, because its members were clerks, but it could be turbulently independent even in the face of the Pope. There were benefactors—munificent benefactors—who founded great colleges within the universities; but though they were fond of making statutes for the government of their colleges, they left opinion alone, for the simple reason that there was no need for any sort of control. The curriculum was largely a traditional curriculum in the arts; and if theology was sometimes fertile of heresies, there was, at any rate, only a single Catholic Church, and all men were members of one communion. The modern university is set in a far more tangled web of environment. It is an object of lively interest to the State, which may sometimes exert, or seek to exert, a control of its teachers and its teaching, and may at any rate (I speak of Great Britain) appoint Royal Commissions to inspect and statutory commissions to reform its organisation. Local authorities—a dominion in Canada; a county or city in England—may interest themselves deeply in what they regard as a local university. Benefactions and endowments from private sources may play a large part in determining the extent and the direction of university development. A Labour party may demand that the universities shall undertake extra-mural work among the working classes; an organisation such as our National Union of Teachers may ask that the universities shall make it their policy to accept and train as graduates all the members of the teaching profession in the country. What has become of the free guild of the Middle Ages? And should the free guild of the Middle Ages be our modern ideal?

No modern university can have anything of the freedom of a mediæval university. The mediæval university stood alone; the modern university is part of a great educational system which embraces the whole community. It cannot control the lower ranges of this system—the elementary and secondary schools—or demand that the work done in those ranges shall be simply preparatory to its own work as conceived and determined by itself; for a majority of the students in the lower ranges will never come to the universities, and their studies must be organised as ends in themselves, and not as means or propædeutics to work in the university. The university has to adjust itself to the educational system, and not the educational system to itself. That educational system is the result of a social ideal, and that social ideal is in the last resort defined by Parliament. The university is therefore bound to conform to the social ideal adopted by Parliament and expressed in the educational system. It has the one consolation of hoping that by its thinking and teaching it is a great force in forming the social ideal by which it is itself controlled. In English-speaking countries, at any rate, the final authority of the State is not an enemy to the freedom of the university. A much more dangerous enemy is social interests, especially when they are backed by the power of cash. We may not believe in more than $\frac{5}{8}$ of the argument of *The Goose Step*, in which Mr. Upton Sinclair draws his lurid picture of the bogey of social interests. But even with a discount of $\frac{3}{8}$, or more, he is alarming.

It is a saying current in universities—and, I dare say, everywhere else—that finance determines policy. It is certainly true that the methods by which a university secures its revenue cannot be without effect on the freedom with which it develops its policy of education. In no university—not even in Oxford and Cambridge—does the student pay the whole, or anything like the whole, of the cost of his education. In the newer English universities we may say that, on the average, the student provides $\frac{3}{10}$ of the cost of the running of his university. The remaining $\frac{7}{10}$ has to be found from other sources. Before we look at those other sources, we may venture on a general observation. The persons or bodies who provide the required $\frac{7}{10}$ may be inspired by a variety of motives. We may put first the motive of advancing the cause of truth and promoting the higher education of the best minds of the community. But we must allow for the entry of other motives. A university is, we may say, a great pulpit; and there will also be some who desire to 'tune the pulpits,' and to make the preachers say acceptable things. It is another current saying that those who pay the piper call the tune. We should be shutting our eyes to a genuine danger if we did not admit the possibility of 'tuning.' And if we regard it as an undesirable possibility, we must be ready with suggestions for its avoidance or, at any rate, its diminution.

There are three possible sources of university revenues. One is the fees of students: a second is private benefaction: a third is public assistance, whether from the national or the local authority. It is a desirable thing that universities should continue to draw an income from the fees of their students. It is earned income: it is independent money. It is good both for the university and its student, making the one feel that it earns as well as spends, and the other that he gives as well as receives. It is indeed a pity that any system of fees should exclude a single student

of promise from a university. But a proper system of national and local scholarships (which should include maintenance, where it is necessary, as well as fees) will prevent any such exclusion. Granted, therefore, such a system of scholarships, there seems to be every reason for maintaining university fees which provide from $\frac{3}{10}$ to $\frac{2}{5}$ of the income of a university. They help to give the university self-respect and independence: they may help to give the same qualities to students.

The second source of income, which takes the form of private benefaction, has its fine and attractive side. When one listens, in the bidding prayers of the old English universities, to the names of the benefactors of dead and bygone centuries, one cannot but be proud of a great tradition long and truly maintained. And again, when one thinks of the paucity of private benefaction to universities in England to-day, and contrasts the abounding munificence of many cheerful givers in the United States, one cannot but feel abashed. Yet there is some reason for feeling that, in modern democratic communities, there is a limit to the extent to which private benefaction can safely endow universities. Universities are great public institutions. They belong to the general commonwealth. They cannot be proprietary. They cannot be sectarian. They must be above even the suspicion of belonging to one or other side in our social cleavage. They belong to both. A university which relies to any great extent on private benefaction may tend, however unconsciously, to teach and to preach acceptable things; and that is the greatest offence which it can commit against the spirit of truth. To take benefaction if it comes, but not to go out to seek it; to look even a gift-horse in the mouth with a modest and discreet inquiry; to be sure that no endowment contravenes by one jot or tittle freedom of inquiry or freedom of expression—these are the natural policies of a university which respects its own genius of academic freedom. I would not exaggerate the dangers of private benefaction to universities. Often and often it is the fruit of plain and unconditioned generosity. But I would not be blind to the possible dangers. And it is always possible that private benefactions may have their tacit implications—a form of capitalism; a particular kind of nationalism; some brand of confessionalism—which may make them enemies of academic freedom.

I come, in conclusion, to the third source of university revenue, which is that of public assistance from the local or national authority. If our universities are truly great public institutions, subject (as they are in England) to visitation by the State and to reformation by the State, they must be a charge on the public revenues for that part of their expenditure which they cannot earn by fees from their students or receive in gifts from private endowments. In our English system the aid given to education from public funds (whether the education be elementary, or secondary, or university) is always two-fold. Part comes from the local authority—the county or borough council: part comes from the national exchequer. The two co-operate: they bargain, and often dispute, about their respective shares. Sometimes education suffers from their disputes; but in many ways (and not least in universities) it gains from the presence and joint action of the two authorities. The national authority may stimulate a local authority to increase its contribution; the local authority may attach conditions to its contributions which keep the national authority within due limits of action. There is a certain gain in the system of check

and counter-check between local and national authorities. It is more favourable to universities than a system in which there is only a single public authority. It is sometimes a little of a trouble (and in a moment of irritation one might even describe it as a nuisance) that both authorities are apt to crave information about the same point on different schedules. But the gain is much greater than the loss.

The aid which is given by the national authority to universities in Great Britain is at the present time much greater than that which is given by the local authority.[3] And it is given on a singularly liberal scheme. An annual sum of £1,250,000 is distributed by a Treasury Committee of independent scholars among the universities in the shape of block grants, which each university is free to spend along the lines of its own policy. Only in the sphere of medical education, and in respect of the grants made to medical schools, has any specific educational condition been attached. Here the policy of favouring the system of clinical units has been adopted by the Committee, and that policy has its critics. That, however, is the only action which even smacks of interference. The aid given by local authorities is hardly given on so liberal a scheme. Local authorities are apt to regard universities as their own local institutions which they should control to a greater or less degree; and they sometimes allocate their aid to specific purposes only, or attach very definite conditions to their grants. So long as their grants are definitely less than those of the national authority, and so long as there is the dualism of the local and the national authorities, no serious alarm need be felt. At the same time one cannot but feel that the local authorities are inclined to press too far the idea that 'democratic control' of university education means its control by elected local representatives assembled in county or borough council. We may rejoin that democratic control of a university is control by its own governing body, provided that that body is democratically constituted, and is duly subject in serious matters to public criticism. And the Treasury Committee, which virtually proceeds on that conception, seems closest to genuine democratic principles.

On the whole, there is no serious menace to academic freedom in Great Britain from a system of university finance which relies, as our system does, on a balanced mixture of income from fees, public assistance, and private benefaction, with the balance perhaps inclining more and more to a preponderance of public assistance. Much, however, depends on the dualism of our system of public assistance, and much too on our habit of leaving institutions alone, to go their own way, as far as possible. The present position is very tolerably good, and the general English notion of self-government leaves our universities as free as it is good for them to be. There might conceivably arise a government, strongly wedded to definite principles, which refused to give aid to universities unless those principles were taught, or were not, at any rate, neglected in the instruction given by the universities. An advanced Labour Government, for instance, might possibly take objection to the teaching by a university of what, in its view, were 'capitalistic' economics, and the omission of the economics of Socialism. But the possibility is most exceedingly improbable—unless the

[3] In England and Wales, during the academic year 1922-1923, the percentage of the total income of universities due to grants from Parliament was 38·1: that of total income arising from grants made by local authorities was 14·4.

professors of economics are exceedingly injudicious. We may safely conceive our universities as already, and likely to be more and more, great public institutions, deriving their income in increasing measure without any diminution of freedom from the State and the local authorities. It is to be hoped that the teachers of our universities will *pari passu* conceive themselves (as I believe they increasingly do) as lovers, seekers and preachers of pure knowledge for its own sake, vowed to no party when they speak from the chair, and rising above party so far as they can in all that they say or do in civic affairs outside.

SECTION M.—AGRICULTURE.

PRESENT-DAY PROBLEMS IN CROP PRODUCTION.

ADDRESS BY

SIR E. JOHN RUSSELL, F.R.S.,

PRESIDENT OF THE SECTION.

The visits of the British Association to Canada have hitherto very appropriately coincided with definite stages in the progress of agricultural science and practice. It was at the Montreal Meeting of 1884 that Lawes and Gilbert presented their well-known paper on the sources of the fertility of Manitoba soils which ended the first great period of the development of agricultural science. This period had lasted eighty years; it had been ushered in with the precise and scientific work of de Saussure published in 1804; its outstanding features had been the foundation of agricultural science by Boussingault in 1834, its enrichment by Liebig's brilliant essay of 1840, and its systematic development by Lawes and Gilbert at Rothamsted from 1843 onwards. The whole purpose of the scientific workers of the period was to feed the plant; in Gilbert's own words the message of the crops on the Rothamsted plots was, 'If you won't feed us we won't grow.' The success of the new science was remarkable; its great triumph was the discovery of artificial fertilisers and their introduction into farming practice, and the workers had the great joy of seeing the crop yields rise considerably as the direct and recognised result of their labours. The problems were largely chemical, and agricultural science was regarded as simply a branch of chemistry. Gilbert's paper in 1884 was read before the Chemical Section, and it presented soil fertility as essentially chemical; a fertile soil, he argued, is one containing much plant food, especially nitrogen; it is one 'which has accumulated within it the residues of ages of natural vegetation, and it becomes infertile as this residue is exhausted.' At the time of the Toronto Meeting in 1896 a new period had begun, quietly and unnoticed, but growth was so rapid that at the Winnipeg Meeting in 1909 the subject had grown right away from chemistry; it had become a definite subsection, and its importance was so widely recognised that a recommendation was passed asking the Council to set it up as a full section, which was subsequently done.

In this second period the purpose was not to feed the crop but to study it; to discover what factors are concerned in the growth of crops and how they operate. This period, which may be called the period of free exploration, since the workers were not usually tied down to any particular technical problem, began almost simultaneously in the United States, in France, and in Germany. As soon as agricultural science was studied in the United States it became evident that the cultivation of the soil was at

least as important as the feeding of the crop. This fact had of course been fully recognised in the English experiments, but the English farmer was so skilled in cultivation that he could be taught but little by science. The early American work as developed by Kedzie at Michigan, King at Wisconsin, Hilgard, and Whitney, was largely physical, and it greatly widened the outlook of agricultural investigators, opening the way to the extensive physical and physico-chemical studies which have now become so characteristic a feature of American work. The French investigators, particularly Schloesing, Muntz, Berthelot, and Déhérain, and the brilliant Russian, Winogradsky, then in Paris, revealed a new world of soil micro-organisms, the wonder and mystery of which appealed to the imagination of the younger workers in a way that none of the older utilitarian work had done. The Germans methodically explored the fields thus opened up; Hellriegel and Wollny accumulated a mass of data as to plant growth and soil changes which still remains of value to the student. These pioneers were succeeded by a host of followers whom it would be impossible to enumerate at length, and from whom it would be invidious to select a few. Moreover, the chemists and physicists of the old school were no longer left in sole possession; van Bemmelen introduced the conception of colloids, and at a later date Mitscherlich, Baule, and others developed the idea of mathematical expressions for the data of agricultural science. Sachs and his pupils in Germany, Déhérain, Maquenne and Demoussy in France, joined up the new science of plant physiology with agricultural science. The plant breeder also came in; Gregor Mendel's work, after lying hidden for forty years, was revealed to the world by Bateson and was at once turned to agricultural use in England by one of Marshall Ward's pupils, R. H. Biffen; and in the United States by Webber and others. The selection method was developed to a high pitch of perfection in Canada by William Saunders, a revered leader in our science, whose dignified presence and kindly words of greeting remain as a vivid recollection of our visit fifteen years ago. His mantle has fallen on his son Charles, who has continued and developed the work.

The result of all this effort has been the accumulation of an enormous mass of information covering a very large part of the field with which agriculture has to deal. It has been essentially a pioneer period, with all the advantages of keen individual interest, controversy, sometimes even of excitement; but also with the disadvantages of a certain lack of perspective, failure to follow up important issues and some narrowness of outlook inevitable when a single individual is working alone at a great subject.

Generalisations that have emerged.

But in spite of these drawbacks several important generalisations have emerged. One of the most pregnant in possibilities for the future is the recognition that the plant is a very plastic organisation and can be modified to a considerable extent within certain limits. Two methods are adopted: breeding, which may be on observational lines or on the Mendelian method of picking out the desired unit characters from plants in which they occur and assembling them in a new plant; and selection, in which a desirable plant is caused to produce seed from which stocks are multiplied. The scientific problems fall within the province of the science of genetics;

the practical significance of the work lies in the fact that it greatly simplifies the agricultural problem by providing plants more or less suitable to the existing natural conditions where otherwise the expert would have the difficult, if not impossible, task of making the conditions suit the available plants. The work has proved extraordinarily fruitful and has given astonishing results even in our own time. It has played no small part in the amazing development of wheat growing in Canada. When the British Association went to Winnipeg in 1909 we were all impressed by the fact that Canada had then passed the 160-million bushel mark in production, but who would have thought that within fourteen years the production would exceed 474 million bushels? Even in England, where wheat has been grown for 2,000 years, and where farmers have a long traditional knowledge of the crop, the new varieties introduced by Biffen have increased the yields and the certainty of yields. The triumphs of Webber and others in the United States, of Nielson Ehle with cereals in Sweden, Jeffreys in standardising the quality of cotton in Egypt, the Howards in producing wheats for India, to mention only a few, are still fresh in our minds. In the first period in the development of agricultural science the honours in the matter of practical applications lay with the chemists for the artificial manures, but in the present period we must admit that they lie with the plant breeders and selectors who, indeed, are only on the threshold of what they may yet accomplish. And this great practical purpose of finding or producing varieties of crops specially suited to local conditions would be further advanced if the work were done in co-operation with plant physiologists who could precisely define the modifications required. Much saving of time and effort could be effected if it were possible to set up some International garden where small quantities of the plant breeders' productions could be grown, including those which each one has rejected as being unsuitable to his particular requirements. Many of these unwanted outcasts might prove of value in other conditions.

A second generalisation is that the soil is not a fixed, constant thing, but is pulsating with change. It contains a great population of micro-organisms which, among other activities, decompose the dead plant residues, producing nitrates, humic and other substances of great importance in crop production. But the numbers of these organisms fluctuate continually, and the bacteria at least change hourly; the nitrates suffer equally rapid changes in amount. Even the mineral part of the soil is not constant in composition. Modern research work shows that many of the properties determining fertility in soils are due to the soil colloids, and some of the most important are attributable to calcium complexes. These are unstable and are affected by the soil water. If the water is free from salts but contains carbon dioxide, the calcium may be replaced by hydrogen, and an acid soil results; if the water contains sodium chloride, the calcium is replaceable by sodium and the resulting complex may readily give rise to an alkali soil. So far as is known, the changes are governed by the ordinary stoichiometric laws, the equilibrium following the usual course expected when a colloid is concerned. But the important fact emerges that any soil not well supplied with calcium contains within itself the possibility of becoming acid and therefore infertile, or alkaline and probably sterile, according to the nature of the soil water soaking through it. The various biological and chemical changes tend to alter the composition of the soil

solution. Apparently, however, the colloids have a steadying or 'buffering' effect, reducing the degree of acidity caused by the production of acids and absorbing or precipitating various ions that might otherwise cause disturbances.

A third important generalisation that has emerged is that the relations of the plant and the soil are not rigidly fixed but are capable of considerable variation, being profoundly influenced by a third factor, the climate. A soil moderately fertile in one set of conditions may be relatively unproductive in another. This happens repeatedly with soils containing much clay or much coarse sand. In Table I. are given the mechanical analyses of two soils, one of which, the Lias clay from England, is quite unworkable and remains derelict under our conditions of cool temperature and moderate but frequent rainfall, by reason of its high content of clay and fine silt; while the other, which contains even more clay, is capable of carrying good crops of grain and cotton under the hot dry conditions of the Sudan. The Western prairie soil is of similar physical type to that of the English Weald soil, but while the prairie soil under its climatic conditions of warm dry summer and cold dry winter is, and is likely to remain, a fertile wheat producer, the Weald soil under the wetter conditions of England is less fertile. In hot dry conditions the clay is no disadvantage and may even be an advantage, but in wet conditions it becomes a serious drawback; indeed, it might be possible to find some mathematical relationship between rainfall and degree of objectionableness in clay.

TABLE I.

Soils of similar type as regards mechanical analysis, but varying greatly in fertility by reason of climatic differences.

	Rich in finer fractions				Rich in coarser fractions	
	Waste land very difficult of cultivation	Fertile soil, millet & cotton	Poor farm land difficult to cultivate	Good prairie soil, Wheat	Waste land, Norfolk	Market garden, Anglesey
	Lias clay Oxfordshire	Sudan	Weald clay, Kent	Brandon	22 in. rain	35 in. rain
Coarse sand, 2.0 to 0.2 mm.	0·7	7·6*	1·5	2·5	62·4	93·7
Fine sand, 0.2 to 0.04 mm.	2·0	20·9	11·0	15·4	25·7	2·8
Silt, 0.04 to 0.01 mm.	6·4	} 12·6	19·6	17·7	0·2	0·5
Fine silt, 0.01 to 0.002 mm.	22·0		26·8	16·1	1·8	0·4
Clay (below 0·002 mm.)	41·0	55·9	22·1	29·2	0·6	Nil

* Mainly black nodules of calcium carbonate.

It appears then that if a fertile soil were carried from one country to another its productive power would not necessarily be carried with it. Its fertility is, to a considerable extent, dependent on the fact that it fits in with the climatic factors in producing conditions favourable to good growth of desirable crops.

Complexity of the Problem : Methods of Attack.

The agricultural investigator is thus confronted with three closely interlocking agencies—the plant, the climate, and the soil—each of which is variable within certain limits, and each playing a large part in the crop production which it is his business to study.

Confronted with a problem of this degree of complexity there are two methods of procedure : the empirical method of field observations and experiments, in which there is no pretence of great refinement and no expectation that the same result will ever be obtained twice, it being sufficient if over an average of numerous trials a result is obtained more often than would be expected from the laws of chance ; and the scientific method, in which the factors are carefully analysed and their effects studied quantitatively ; a synthesis is then attempted, and efforts are made to reconstruct the whole chain of processes and results. The scientific method is, of course, the one to which we are naturally attracted. But common truthfulness compels one to admit that up to the present the greatest advances in the actual production of crops have been effected by the empirical method, and not infrequently by men who are really artists rather than men of science, in that they are guided by some intuitive process which they cannot explain, and that they have the vision of the result before they obtain it, which the scientific man commonly has not.

The best hope for the future lies in the combination of the empirical and the scientific methods. This is steadily being accomplished by the recent strong infusion of science into the art of field experimentation, which has much enhanced the value of the field work and the trustworthiness of its results. Modern methods of replication, such as have been worked out at Rothamsted, and in the United States by Harris of the Carnegie Trust (Cold Spring Harbor), Kiesselbach in Nebraska, Myers and Love of Cornell, and others, constitute a marked improvement in plot technique. And the figures themselves, besides being more accurate, can be made to yield more information than was formerly the case.

Great advances have been made in the methods of analysing the results. The figures are never the same in any two seasons, since the climatic conditions profoundly affect the yields. A few men, like J. H. Gilbert, have the faculty of extracting a great deal of information from a vast table of figures, but in the main even the trained scientific worker can make very little of them. The reason is that he has been brought up to deal with cases where only one factor is varying, while the growth of plants involves the interaction of three variable factors : the plant, the soil, and the climate. It is impossible to apply in the field the ordinary methods of the scientific investigator where single factors alone are studied ; very different methods are needed, adapted to the case where several factors vary simultaneously.

Fortunately for agricultural science, statisticians have in recent years worked out methods of this kind, and these are being modified and developed by R. A. Fisher and Miss Mackenzie for application to the Rothamsted field data. It so happens that this material is very suitable for the purpose, since a large number of the field experiments have been repeated every year for seventy or eighty years on the same crop and on the same piece of land, using the same methods ; the field workers also remain the same for many years, the changes being rare and without break in continuity.

Although the statistical investigation is only recently begun, mathematical expression has already been given to the relationship between rainfall and yield of wheat and barley under different fertiliser treatments, and precision has been given to some of the ideas that have hitherto been only general impressions. If on an average of years a farmer is liable to a certain distribution of rainfall, it is becoming possible to advise as to fertiliser treatment which enables the plant to make the best of this rainfall.

Unfortunately, few other Experimental Stations possess such complete masses of data as Rothamsted. Methods are now being devised, however, both by Fisher and by the able English investigator who modestly conceals his identity under the pseudonym 'Student,' for the study of smaller numbers of data, and it is hoped that these or others equally effective will be applied to the results of field experiments accumulated at various Experimental Stations throughout the world. A massed attack by a competent band of statisticians on the whole of the data of the best Experimental Stations, dealing with yields of crops under different conditions of nutrient supply, temperature, rainfall and other factors that go to make up the aggregate called season, would yield information of extraordinary value.

Investigations of this kind, however, are necessarily slow, and they do not themselves afford complete information; their value lies in the fact that they reduce a very complex problem to a set of single-factor problems of the type with which the scientific investigator is already familiar. In the meantime, while this work is proceeding, much is being done by observational methods. At Rothamsted the field plots are under continual observation by a group of three workers, a physiologist, an ecologist, and an agriculturist, who study such factors as rate or habit of growth, earliness of starting or maturing, degree of resistance to insect or fungus attack; their observations are fully recorded and brought before the chemical, physical and botanical departments at regular and frequent intervals. Certain of the experiments are repeated at other centres on closely similar lines for purposes of comparison. In consequence our old field plots which have been studied for the past eighty years by Lawes, Gilbert, Warington, and Hall, and might have been supposed to have no further tales to tell, are found to be still yielding results of great interest in agricultural science and practice.

The Results Obtained: Alterations in the Plant.

We shall begin with the results obtained by effecting alterations in the plant. Reference has already been made to the changes brought about by the plant breeder, and we need not stop to argue whether the great improvements in crops made in pre-Mendelian days by the Suttons and Findlay in potatoes, by Chevalier in barley, by the Gartons in oats, Vilmorin in sugar beet, and others, should be labelled empirical or scientific. There are certain other changes in plants, however, of a purely temporary nature, which have been induced by changes in conditions. It is a commonplace among farmers that certain soil conditions influence not only the yield but also the quality of crops. The leaf and root are more easily affected than the seed. The case of mangolds has been investigated at Rothamsted; the sugar content of the root, an important factor in determining feeding value, was increased by increasing the supply of potassium to the crop. Middleton at Cockle Park showed that grass increased in feeding value—

quite apart from any increase in quantity—when treated with phosphates. Potatoes are considerably influenced by manuring; increasing the supply of potassium influences the composition of the tubers and also that much more impalpable quality—the cook's estimate of the value of the potato; while we have found at Rothamsted that a high-class cook discriminated between potatoes fertilised with sulphate of potash and those fertilised with muriate of potash, giving preference to the former.

Grain is more difficult to alter by changes in environmental conditions; indeed, it appears that the plant tends to produce seed of substantially the same composition whatever its treatment—with the important exception of variation in moisture supply. Mr. Shutt has explored the possibilities of altering the character of the wheat grain by varying the soil conditions, and finds that increases in soil moisture decrease the nitrogen in the grain. Similar results have been obtained in the United States.

On the other hand, in England the reverse seems to hold, at any rate for barley. This crop is being fully investigated at the present time under the Research Scheme of the Institute of Brewing, because of its importance in the preparation of what is still Britain's national beverage. Increased moisture supply increases the percentage of nitrogen in the grain, and so also does increased nitrogen supply, though to a much less extent; on the other hand, both potassic and phosphatic fertilisers may decrease the percentage of nitrogen, though they do not always do so; the laws regulating their action are unknown to us.

The practical importance of these problems of regulating the composition of the plant lies in the fact that the farmer can control his fertiliser supply, and also to some extent his moisture supply, so that it lies within his power to effect some change should he wish to do so.

The following are the nitrogen contents and the valuations of barley grown in the same season from the same lot of seed on farms only a few miles apart:—

Effect of Moisture.

	Drier soil	Moist land
Nitrogen per cent. in grain	1·44	1·80
Valuation per quarter of 448 lb. ..	52*s*. 5*d*.	41*s*. 6*d*.

Effect of Nutrients.

	No nitrogenous manure	Nitrogenous manure
Nitrogen per cent. in grain	1·379	1·464
Valuation per quarter of 448 lb. ..	53*s*.	52*s*.

At present we know but little about the matter and we are not in a position to advise the farmer as to how he may use these facts to the full advantage. The complete study of the problem necessitates the co-operation of a plant physiologist.

There is another direction also in which alterations in the plant would be of great value if only we knew with certainty how to bring them about.

In agricultural science one sometimes thinks only of the crop and the factors that affect its growth. But in agricultural practice there is often another partner in the concern: a pest or parasite causing disease. The amount of damage done by pests and diseases to agricultural crops is

astounding; in Britain it is probably at least 10 per cent. of the total value of the crops and the loss is probably some 12,000,000*l.* sterling per annum; in some countries it is considerably more. Indeed, the number of insect pests and of harmful fungi and bacteria that skilled entomologists and mycologists have found in our fields might almost lead us to despair of ever raising a single crop, but fortunately the young plant, like the human child, grows up in spite of the vast number of possible deaths. The saving fact seems to be that the pest does harm only when three sets of conditions happen to occur together: the pest must be present in the attacking state; the plant must be in a sufficiently receptive state; and the conditions must be favourable to the development of the pest. It is because this favourable conjunction of conditions comes but rarely that crops manage to survive. And this gives us the key to control if only we knew how to use it. Complete control of any of these three conditions would end all plant diseases. Unfortunately, control is never complete even in glasshouse culture, still less out of doors. But even partial control would be very helpful. All these pests go through life cycles, which are being studied in great detail all over the world, and especially in the United States. Somewhere there occurs a stage which is weaker or more easily controlled than others, and the pest would become harmless if the chain could be broken here or if the cycle could be sufficiently retarded to give the plant a chance of passing the susceptible stage before it is attacked.

The plants themselves, as we have just seen, are in some degree under control, and if they could be pushed through the susceptible stages before the pest was ready they would escape attack. Barley in England is sometimes considerably injured by the gout fly (*Chlorops tæniopus*). The larvæ emerge in spring from the eggs laid on the leaves and invariably crawl downwards, entering the young ear if, as usually happens, it still remains ensheathed in leaves. J. G. H. Frew, at Rothamsted, has shown that early sowing and suitable manuring cause the ear to grow quickly above the track of the larvæ, and thus to escape injury. E. A. Andrews, in India, has found that tea bushes well supplied with potassic fertiliser escape attack from the mosquito bug (*Helopeltis*) for the rest of the season, apparently because bushes so treated become unsuitable as food to the pest. And further, the conditions are alterable. H. H. King, in the Sudan, has effected some degree of control of the cotton thrips (*Heliothrips indicus*) by giving the plant protection against the drying North wind and so maintaining a rather more humid atmosphere—a condition in which the plant flourishes more than the pest. Tomatoes in England suffered greatly from *Verticillium* wilt till it was found that a small alteration of temperature threw the attack out of joint. They are also much affected by stripe disease (*B. lathyri*), but they become more resistant when the supply of potash is increased relative to the nitrogen. It has recently been maintained, though the proof is not yet sufficient, that an altered method of cultivating wheat in England will afford a good protection against bunt. These cultural methods of dealing with plant diseases and pests offer great possibilities, and a close study jointly by plant physiologists and pathologists of the responses of the plant to its surroundings, and the relationships between the physiological conditions of the plant and the attacks of its various parasites, would undoubtedly yield results of great value for the control of plant diseases. Again, however, the plant breeder can save a world of trouble

by producing a variety resistant to the disease; or there may fortunately be found an immune plant from which stocks can be had, as in the case of the potatoes found by Mr. Gough to be immune to the terrible wart disease.

Control of Environmental Factors.

It thus appears that, if only plant breeders and plant physiologists could learn to alter existing plants or to build up new plants in such a way that they should be well adapted to existing soil and climate conditions, and not adapted to receive disease organisms at the time the organisms are ready to come—if only they could do this all agricultural land would become fertile and plant diseases and pests would become ineffective: at any rate until the pests adapted themselves to the new plants. Although no one can set limits to the possibilities of plant breeding and plant physiology, we cannot assume that we are anywhere near this desirable achievement or that we are likely to be in our time. There will always remain the necessity for altering the environmental conditions to bring them closer to the optimum conditions for the growth of the plant. No attempt is yet made in the field to control two of the most important of the factors: the light and the temperature, though it is being tried experimentally. There is a great field for future workers here; at present plants utilise only a fraction of the radiant energy they receive. At Rothamsted attempts have been made by F. G. Gregory to measure this fraction; the difficulties are considerable, but the evidence shows that our most efficient plants lag far behind our worst motor-cars when regarded as energy transformers for human purposes. One hundred years ago the efficiency of an engine as transformer of energy was about 2 per cent.; now, as a result of scientific developments, it is more than 30 per cent. To-day the efficiency of the best field crops in England as transformers of the sun's energy is about 1 per cent.[1]: can we hope for a similar development in the next hundred years? If such an increase could be obtained an ordinary crop of wheat would be about 400 bushels per acre, and farmers would feel sorry for themselves if they obtained only 200 bushels. But we are only at the beginning of the subject. Increases in plant growth amounting to some 20 or 25 per cent. have been obtained by V. H. Blackman in England under the influence of the high-tension electric discharge, which presumably acts by increasing in some way the efficiency of the plant as an energy transformer. Possibly other ways could be found. It needs only a small change in efficiency to produce a large increase in yield. Much could be learned from a study of the mass of data which could be accumulated if agricultural investigators would express their results in energy units as well as in crop yields as at present.

Interesting results may be expected from the attempts now being made in glasshouse culture both in Germany and at Cheshunt to increase the rate of plant growth by increasing the concentration of the carbon dioxide in the atmosphere.

Control of the Soil Factors.

The soil factors lend themselves more readily to control and much has been already achieved. Water supply was one of the first to be dealt

[1] The remaining energy being largely used up in transpiration. This figure refers to the total radiation received by the leaf, and not to the fraction received by the chloroplast surface. For this latter the value is much higher.

with. Civilisation arose in the dry regions of the earth, and as far back as 5,000 years ago irrigation was so advanced as a practical method that it came into the ordinances drawn up by the great Babylonian king Hammurabi. The chief problems at the present time are to discover effective means of economising water and to ascertain, and if possible control, the relationships between the soil, the water, and the dissolved substances in the water. Economical use of water is necessary because it allows larger areas to be irrigated, and because water beyond a certain amount injures the soil and asphyxiates the plant roots. This part of the problem is largely one of engineering and police control. The more serious problem, perhaps the most serious confronting agricultural science to-day, is that presented by the soluble matter in the water and the soil. The terrible spectre of alkali looms ahead of every irrigation project; it may be kept under control for a longer or shorter time or it may completely wreck the scheme. Instances could be multiplied of schemes started with great expectations of results yet yielding only disappointment and loss. A volume could be filled with the tragedies of the alkali problem. Neutral salts, particularly sodium sulphate, are not harmful to plants unless their concentration exceeds a certain critical value; indeed, some of the heavy soils in dry countries, as in Egypt and the Sudan, become unworkable if washed with pure water; they remain flocculated only because some soluble salts are present. Chlorides beyond a critical concentration are more harmful to the plant, but sodium carbonate is deadly, and there is no certain way at present of overcoming its effects.

The empirical method has apparently gone as far as it can, and nothing more can be expected until some fresh opening is discovered by scientific workers.

Almost equally important is the more efficient utilisation of water in districts where the rainfall is sufficiently high to obviate the need for irrigation, but insufficient to allow of any wastage of water. The practical work of the Utah agriculturists as exemplified by Widstoe, and the laboratory results of Keen at Rothamsted, all indicate that something can be done. It is legitimate to hope that the next great advance will come from Canada, where in the West there are admirable opportunities for studying the problem.

Inseparably bound up with water supply are the questions of cultivation and of drainage, which affect not only the water but the air supply to the roots. This former subject is now attracting considerable attention: the great need is to discover means for expressing cultivation in exact physical and engineering units. The measurements of Keen and Haines at Rothamsted, and the chemical work of A. F. Joseph, N. Comber and others on clay, and of Odén, Page, and others on humus, indicate the possibility of finding exact expressions and of effecting co-operation with the workers in the new fields of agricultural engineering.

Another soil factor which readily lends itself to some degree of control is the amount of plant nutrients present. The possibility of increasing this by means of manure has been so frequently explored in field trials that it has sometimes been regarded as almost a completed story; indeed, Rothamsted tradition affirms that Lawes himself once gave orders to have the Broadbalk field experiments discontinued because they had nothing further to tell; it was only the earnest persuasion of Gilbert that caused

him to countermand the order. So far from the subject being exhausted, it still bristles with problems. The new nitrogenous fertilisers, resulting from war-time activities in nitrogen fixation; the need for reducing the cost of superphosphate; the change in character of basic slag; and the Alsatian development in potash production are producing changes in the fertiliser industry the full effects of which are not easy to foresee. Economic pressure is driving the farmer to derive the maximum benefit from his expenditure on fertilisers, lime, farmyard manure and other ameliorating agents, and is compelling a more careful study of possibilities hitherto disregarded, such as the use of magnesium salts, silicates, and sulphur as fertilisers, and, above all, a much more precise diagnosis of soil deficiencies than was thought necessary in pre-war days.

But there are more fundamental problems awaiting solution. It is by no means certain that we know even yet all the plant nutrients. The list compiled by Sachs many years ago includes all needed in relatively large amounts, but Gabriel Bertrand has shown that it is not complete and that certain substances—he studied especially manganese—are essential, although only in very small amounts. Miss Katherine Warington, working with Dr. Brenchley at Rothamsted, has shown that leguminous plants fail to develop in the so-called complete culture solution unless a trace of boric acid is added. Mazé has indicated other elements needed in small amounts.

Another problem needing elucidation is the relationship between the quantity of nutrients supplied and the amount of dry matter produced. Is dry matter production simply proportional to nutrient supply, as Liebig argued, with the tailing off beyond a certain point, as demonstrated by Lawes and Gilbert, or is it always less than this, as indicated by Mitscherlich's logarithmic curve, or is the relationship expressed by one of the more complex sigmoid curves as there is some reason to suppose? We do not know; and the problem is by no means simple, yet it governs the 'diminishing returns' about which farmers now hear so much. Again, very little is known of the relationship between nutrition and period of growth. One and the same quantity of a nitrogenous fertiliser, for example, may have very different effects on the plant according as it is given early or late in life; not only is there a difference in quantity of growth, but also in the character of the growth. Late dressings cause the characteristic dark-green colour to appear late in the season, and thus affect the liability to fungoid diseases; they increase the percentage of nitrogen in the grain and they may give larger increases of crop than early dressings.

Investigations are needed to find the best methods of increasing the supply of organic matter in the soil and its value for the different crops in the rotation.

All these problems will sooner or later find some solution. But there remains a greater problem of more importance than any of them: the linking-up of plant nutrition studies with those of the soil solution. As our cousins in the United States were the first to emphasise, the fundamental agent in the nutrition of the plant is the soil solution, and they have made a remarkable series of investigations into what appeared at one time a hopeless proposition—the physico-chemical interactions between the soil and the soil water. Whitney and Cameron began the work, and it has gone on with much controversy—as important scientific investigations

always do—and it is now being attacked with much vigour by some of the younger scientific workers, particularly in the Californian school: Burd, Hoagland, Kelley, Lipman, Stewart, Sharp, and others. There is also some valuable work by Gola and other Italians. The natural soil solution is not always the best for the growth of plants. It is reasonable to suppose that the most efficient method of using fertilisers would be for making up the soil solution to the optimum composition and concentration for each stage of the growth of the crop. Unfortunately, this cannot yet be done. The added fertiliser does not simply increase the concentration of the soil solution to the precise extent that might be expected; there are interactions, absorptions, and base exchanges of the kind studied first by Way, much later by van Bemmelen and by Gedroiz, and more recently by Hissink and by Wiegner. Further, the plant relationships are not constant; there is apparently—though this is not certain—more response to certain nutrients at one time of its life than at another. A great advance in crop production may be expected when the soil chemists have discovered the laws governing the soil solution, when the plant physiologists can give definite expression to the plant's response to nutrients, and when someone is able to put these results together and show how to alter the soil solution so that it may produce the maximum effect on the plant at the particular time. The new soil chemistry will yet have its triumphs.

The Soil Micro-organisms: Can they be Controlled?

It is now more than forty years since the discovery of the great importance of micro-organisms in determining soil fertility. Practical applications necessarily lag far behind; but already three have been made each of which opens out great possibilities for the future. The long-standing problem of inoculation of leguminous crops with their appropriate organisms has already been solved in one or two of its simple cases, chiefly lucerne on new land, and the new process has helped in the remarkable extension of the lucerne crop in the United States and in Denmark. We believe at Rothamsted that the more difficult English problem is now solved also. Interesting possibilities are opened up by the observation that a preliminary crop of Bokhara clover seems to facilitate the growth of the lucerne.

The organisms effecting decomposition are now coming under control, and are being made to convert straw into farmyard manure (or a material very much like it) without the use of a single farm animal. The process was worked out at Rothamsted, and is being developed by the Adco Syndicate, who are now operating it on a large scale and are already successfully converting some thousands of tons of straw annually into good manure.

The third direction in which control of the soil organisms is being attempted is by partial sterilisation. This process is much used in the glasshouse industry in England, and it has led to considerable increases in crop yields. The older method was to use heat as the partial sterilising agent, and this still remains the most effective, but owing to its costliness efforts have been made to replace it by chemicals. Considerable success has been attained; we have now found a number of substances which seem promising. Some of these are by-products of coal industries; others, such as chlor- and nitro-derivatives of benzene or cresol, are producible as crude intermediates in the dye industry.

The Need for Fuller Co-operation.

Looking back over the list of problems it will be seen that they are all too complex to be completely solved by any single worker. Problems of crop production need the co-operation of agriculturists, plant physiologists, soil investigators, and statisticians. Even plant breeding necessitates the help of a physiologist who can specify just what the breeder should aim at producing. And this gives the key-note to the period of agricultural science on which we have now entered—it is becoming more and more a period of co-operation between men viewing the problem from different points of view. Good individual work will of course always continue to be done, but the future will undoubtedly see a great expansion of team work such as has already led to important results in medical research, and such as we know from our experience at Rothamsted is capable of giving admirable results in agricultural science.

The team work should not be confined to individuals working at the same institution. The world would gain greatly if co-operation such as now exists between the Imperial College Botany School and Rothamsted could be effected between other great institutions devoted to agricultural science in the various countries of the world. To take only one illustration: how much could be accomplished in the study of the very difficult alkali problem if it were possible to organise a team representing such great agricultural stations as, for instance, California and Utah, the Departments of Agriculture of India and other of the great Dominions affected, Rothamsted, Hissink's school, with power to lay down experiments anywhere and money to carry them out. And if extended co-operation of this kind should prove impossible of attainment, much could be done by fostering co-operation between the Agricultural Institutions of the Empire. There are certain great problems which are common to large parts of the Empire where the experience of one part would be of great value to the rest. The institutions in Britain, for example, have experience of problems connected with land long since settled and brought into cultivation, where men must produce 40 or more bushels per acre of wheat and 6 to 10 tons per acre of potatoes to make these crops pay, and where animal husbandry must be run on sound and economic lines. Canada has an unrivalled experience with wheat, and in the Western provinces has a magnificent chance for studying one of the most important problems of the day—the water supply to the crop. Australia, New Zealand, South Africa, East, West, and Tropical Africa, India, the West Indies—to mention only a few in the great family that forms the British Empire—all have their special lines in agricultural development; each has some achievement that can be shown with pride and in the certainty that its study will benefit others. The Empire has already its Conference of Premiers, why should it not have its conference for agricultural science and practice?

With fuller co-operation both of men and of institutions we could do much to overcome the present difficulty in regard to utilising the information we already possess. In the last thirty years an immense stock of knowledge has been obtained as to soils and crops—knowledge that ought to be of supreme value in interpreting the facts of Nature as shown in the field. It is stored in great numbers of volumes which line the shelves of our libraries, and there much of it rests undisturbed in dignified oblivion. In the main it consists of single threads followed out more or less carefully;

only rarely does some more gifted worker show something of the great pattern which the threads compose. But even the most gifted can see but little of the design; the best hope of seeing more is to induce people to work in groups of two or three, each trained in a different school and therefore looking at the problem from a different point; each seeing something hidden from the rest. Unlike art, science lends itself to this kind of team work; art is purely an individual interpretation of Nature while science aims at a faithful description of Nature, all humanistic interpretation being eliminated. There is certainly sufficient good will among the leaders of agricultural science to justify the hope of co-operation; there are probably in existence foundations which would furnish the financial aid.

And that leads to my last point. What is the purpose of it all? Team work, co-operation, the great expenditure of time and money now being incurred in agricultural science and experiment—these are justified only if the end is worthy of the effort. The nineteenth century took the view that agricultural science was justified only in so far as it was useful. That view we now believe to be too narrow. The practical purpose is of course essential; the station must help the farmer in his daily difficulties—which again necessitates co-operation, this time between the practical grower and the scientific worker. But history has shown that institutions and investigators that tie themselves down to purely practical problems do not get very far; all experience proves that the safest way of making advances, even for purely practical purposes, is to leave the investigator unfettered. Our declared aim at Rothamsted is 'to discover the principles underlying the great facts of agriculture and to put the knowledge thus gained into a form in which it can be used by teachers, experts, and farmers for the upraising of country life and the improvement of the standard of farming.'

This wider purpose gives the investigator full latitude, and it justifies an investigation whether the results will be immediately useful or not—so long as they are trustworthy. For the upraising of country life necessitates a higher standard of education for the countryman; and education based on the wonderful book of Nature which lies open for all to read if they but could. How many farmers know anything about the remarkable structure of the soil they till, of its fascinating history, of the teeming population of living organisms that dwell in its dark recesses; of the wonderful wheel of life in which the plant takes up simple substances and in some mysterious way fashions them into foods for men and animals and packs them with energy drawn out of the sunlight—energy which enables us to move and work, to drive engines, motor-cars, and all the other complex agencies of modern civilisation? No one knows much of these things; but if we knew more, and could tell it as it deserves to be told, we should have a story that would make the wildest romance of human imagination seem dull by comparison and would dispel for ever the illusion that the country is a dull place to live in. Agricultural science must be judged not only by its material achievements, but also by its success in revealing to the countryman something of the wonder and the mystery of the great open spaces in which he dwells.

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